REPORT

OF THE

EIGHTIETH MEETING OF THE

BRITISH ASSOCIATION

FOR THE ADVANCEMENT OF SCIENCE

SHEFFIELD: 1910

AUGUST 31—SEPTEMBER 7

LONDON
JOHN MURRAY, ALBEMARLE STREET
1911

Office of the Association, Burlington House, London, W.

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PATRON.

HIS MAJESTY THE KING.

PRESIDENT.

Rev. Professor T. G. BONNEY, Sc.D., LL.D., F.R.S.

VICE-PRESIDENTS.

The Right Hon. the Lord Mayor of Sheffield, The EARL FITZWILLIAM, D.S.O.
The Master Cutler of Sheffield, HERBERT BARBER.
His Grace the LORD ARCHBISHOP OF YORK, D.D.
His Grace the DUKE OF NORFOLK, E.M., K.G., G.C.V.O., Litt.D., Chancellor of Sheffield University.
The Right Hon. the EARL OF HAREWOOD, K.C.V.O., Lord-Lieutenant of the West Riding of Yorkshire.
Alderman GEORGE FRANKLIN, Litt.D., J.P., Pro-Chancellor of Sheffield University.
Sir CHARLES ELIOT, K.C.M.G., C.B., Vice-Chancellor of Sheffield University.
Alderman H. K. STEPHENSON, J.P., Deputy Lord Mayor of Sheffield.
The Right Rev. J. N. QUIRK, D.D., Lord Bishop of Sheffield.
A. J. HOBSON, President of the Sheffield Chamber of Commerce.
Alderman Sir WILLIAM CLEGG, J.P., Chairman of the Sheffield Education Committee.
Colonel HERBERT HUGHES, C.M.G., J.P.
Professor W. M. HICKS, Sc.D., F.R.S.
Rev. E. H. TITCHMARSH, M.A., President of the Sheffield Free Church Council.

PRESIDENT ELECT.

Professor Sir W. RAMSAY, K.C.B., Ph.D., LL.D., D.Sc., M.D., F.R.S.

VICE-PRESIDENTS ELECT.

H.R.H. The PRINCESS HENRY OF BATTENBERG.
Alderman T. SCOTT FOSTER, J.P., Mayor of Portsmouth.
His Grace the LORD ARCHBISHOP OF CANTERBURY, G.C.V.O., D.D.
His Grace the LORD ARCHBISHOP OF YORK, D.D.
The Most Hon. the MARQUESS OF WINCHESTER, Lord Lieutenant of the County of Hampshire.
Field Marshal the Right Hon. the EARL ROBERTS, K.G., K.P., G.C.B., O.M., V.C.
The Right Rev. the LORD BISHOP OF WINCHESTER, D.D.
The Right Hon. LORD MACNAGHTEN, G.C.M.G.
Admiral the Hon. Sir A. G. CURZON-HOWE, G.C.V.O., K.C.B., C.M.G.
Major-General J. K. TROTTER, C.B., C.M.G.
Rear-Admiral A. G. TATE, R.N.
Colonel Sir W. T. DUPREE, D.L., V.D., J.P.

GENERAL TREASURER.

Professor JOHN PERRY, D.Sc., LL.D., F.R.S.

GENERAL SECRETARIES.

Major P. A. MACMAHON, R.A., D.Sc., F.R.S. | Professor W. A. HERDMAN, D.Sc., F.R.S.

ASSISTANT SECRETARY.

O. J. R. HOWARTH, M.A., Burlington House, London, W.

CHIEF CLERK AND ASSISTANT TREASURER.

H. C. STEWARDSON, Burlington House, London, W.

LOCAL TREASURER FOR THE MEETING AT PORTSMOUTH.

Alderman T. SCOTT FOSTER, J.P., Mayor of Portsmouth.

LOCAL SECRETARIES FOR THE MEETING AT PORTSMOUTH.

G. HAMMOND ETHERTON. | Dr. A. MEARNS FRASER.

[P.T.O.

ORDINARY MEMBERS OF THE COUNCIL.

ABNEY, Sir W., K.C.B., F.R.S.
ANDERSON, TEMPEST, M.D., D.Sc.
ARMSTRONG, Professor H. E., F.R.S.
BOWLEY, A. L., M.A.
BROWN, Dr. HORACE T., F.R.S.
BRUNTON, Sir LAUDER, Bart., F.R.S.
CLOSE, Colonel C. F., R.E., C.M.G.
CRAIGIE, Major P. G., C.B.
CROOKE, W., B.A.
DYSON, F. W., F.R.S.
GLAZEBROOK, Dr. R. T., F.R.S.
HADDON, Dr. A. C., F.R.S.
HALL, A. D., F.R.S.
HARTLAND, E. SIDNEY, F.S.A.
MARR, Dr. J. E., F.R.S.
MITCHELL, Dr. P. CHALMERS, F.R.S.
MYRES, Professor J. L., M.A.
POULTON, Professor E. B., F.R.S.
PRAIN, Lieut.-Colonel D., C.I.E., F.R.S.
SHERRINGTON, Professor C. S., F.R.S.
SHIPLEY, Dr. A. E., F.R.S.
TEALL, J. J. H., F.R.S.
THOMPSON, Dr. SILVANUS P., F.R.S.
TUTTON, Dr. A. E. H., F.R.S.
WHITE, Sir W. H., K.C.B., F.R.S.

EX-OFFICIO MEMBERS OF THE COUNCIL.

The Trustees, past Presidents of the Association, the President and Vice-Presidents for the year, the President and Vice-Presidents Elect, past and present General Treasurers and General Secretaries, past Assistant General Secretaries, and the Local Treasurers and Local Secretaries for the ensuing Annual Meeting.

TRUSTEES (PERMANENT).

The Right Hon. Lord AVEBURY, D.C.L., LL.D., F.R.S., F.L.S.
The Right Hon. Lord RAYLEIGH, M.A., D.C.L., LL.D., F.R.S., F.R.A.S.
Sir ARTHUR W. RÜCKER, M.A., D.Sc., LL.D., F.R.S.

PAST PRESIDENTS OF THE ASSOCIATION.

Sir Joseph D. Hooker, G.C.S.I.
Lord Avebury, D.C.L., F.R.S.
Lord Rayleigh, D.C.L., F.R.S.
Sir H. E. Roscoe, D.C.L., F.R.S.
Sir A. Geikie, K.C.B., Pres. R.S.
Lord Lister, D.C.L., F.R.S.
Sir William Crookes, O.M., F.R.S.
Sir W. Turner, K.C.B., F.R.S.
Sir A. W. Rücker, D.Sc., F.R.S.
Sir James Dewar, LL.D., F.R.S.
Sir Norman Lockyer, K.C.B., F.R.S.
Arthur J. Balfour, D.C.L., F.R.S.
Sir George Darwin, K.C.B., F.R.S.
Sir E. Ray Lankester, K.C.B., F.R.S.
Sir David Gill, K.C.B., F.R.S.
Dr. Francis Darwin, F.R.S.
Sir J. J. Thomson, F.R.S.

PAST GENERAL OFFICERS OF THE ASSOCIATION.

Sir F. Galton, D.C.L., F.R.S.
P. L. Sclater, Ph.D., F.R.S.
Prof. T. G. Bonney, Sc.D., F.R.S.
A. Vernon Harcourt, F.R.S.
Sir A. W. Rücker, D.Sc., F.R.S.
Prof. E. A. Schäfer, F.R.S.
Dr. D. H. Scott, M.A., F.R.S.
Dr. G. Carey Foster, F.R.S.
Dr. J. G. Garson.

AUDITORS.

Sir Edward Brabrook, C.B.
Professor H. McLeod, F.R.S.

RULES OF THE BRITISH ASSOCIATION.

[*Adopted by the General Committee at Leicester*, 1907, *with subsequent amendments.*]

Chapter I.

Objects and Constitution.

1. The objects of the British Association for the Advancement of Science are: To give a stronger impulse and a more systematic direction to scientific inquiry; to promote the intercourse of those who cultivate Science in different parts of the British Empire with one another and with foreign philosophers; to obtain more general attention for the objects of Science and the removal of any disadvantages of a public kind which impede its progress. Objects.

The Association contemplates no invasion of the ground occupied by other Institutions.

2. The Association shall consist of Members, Associates, and Honorary Corresponding Members. Constitution.

The governing body of the Association shall be a General Committee, constituted as hereinafter set forth; and its affairs shall be directed by a Council and conducted by General Officers appointed by that Committee.

3. The Association shall meet annually, for one week or longer, and at such other times as the General Committee may appoint. The place of each Annual Meeting shall be determined by the General Committee not less than two years in advance; and the arrangements for these meetings shall be entrusted to the Officers of the Association. Annual Meetings.

Chapter II.

The General Committee.

1. The General Committee shall be constituted of the following persons:— Constitution.

(i) *Permanent Members*—

(*a*) Past and present Members of the Council, and past and present Presidents of the Sections.

(b) Members who, by the publication of works or papers, have furthered the advancement of knowledge in any of those departments which are assigned to the Sections of the Association.

(ii) *Temporary Members*—

(a) Vice-Presidents and Secretaries of the Sections.
(b) Honorary Corresponding Members, foreign representatives, and other persons specially invited or nominated by the Council or General Officers.
(c) Delegates nominated by the Affiliated Societies.
(d) Delegates—not exceeding altogether three in number—from Scientific Institutions established at the place of meeting.

Admission.

2. The decision of the Council on the qualifications and claims of any Member of the Association to be placed on the General Committee shall be final.

(i) Claims for admission as a Permanent Member must be lodged with the Assistant Secretary at least one month before the Annual Meeting.
(ii) Claims for admission as a Temporary Member may be sent to the Assistant Secretary at any time before or during the Annual Meeting.

Meetings

3. The General Committee shall meet twice at least during every Annual Meeting. In the interval between two Annual Meetings, it shall be competent for the Council at any time to summon a meeting of the General Committee.

Functions.

4. The General Committee shall

(i) Receive and consider the report of the Council.
(ii) Elect a Committee of Recommendations.
(iii) Receive and consider the report of the Committee of Recommendations.
(iv) Determine the place of the Annual Meeting not less than two years in advance.
(v) Determine the date of the next Annual Meeting.
(vi) Elect the President and Vice-Presidents, Local Treasurer, and Local Secretaries for the next Annual Meeting.
(vii) Elect Ordinary Members of Council.
(viii) Appoint General Officers.
(ix) Appoint Auditors.
(x) Elect the officers of the Conference of Delegates.
(xi) Receive any notice of motion for the next Annual Meeting.

*Chapter III.

Committee of Recommendations.

1. * The *ex officio* Members of the Committee of Recommendations are the President and Vice-Presidents of the Association, the President of each Section at the Annual Meeting, the Chairman of the Conference of Delegates, the General Secretaries, the General Treasurer, the Trustees, and the Presidents of the Association in former years. Constitution.

An Ordinary Member of the Committee for each Section shall be nominated by the Committee of that Section.

If the President of a Section be unable to attend a meeting of the Committee of Recommendations, the Sectional Committee may appoint a Vice-President, or some other member of the Committee, to attend in his place, due notice of such appointment being sent to the Assistant Secretary.

2. Every recommendation made under Chapter IV. and every resolution on a scientific subject, which may be submitted to the Association by any Sectional Committee, or by the Conference of Delegates, or otherwise than by the Council of the Association, shall be submitted to the Committee of Recommendations. If the Committee of Recommendations approve such recommendation, they shall transmit it to the General Committee; and no recommendation shall be considered by the General Committee that is not so transmitted. Functions.

Every recommendation adopted by the General Committee shall, if it involve action on the part of the Association, be transmitted to the Council; and the Council shall take such action as may be needful to give effect to it, and shall report to the General Committee not later than the next Annual Meeting.

Every proposal for establishing a new Section or Sub-Section, for altering the title of a Section, or for any other change in the constitutional forms or fundamental rules of the Association, shall be referred to the Committee of Recommendations for their consideration and report.

3. The Committee of Recommendations shall assemble, for the despatch of business, on the Monday of the Annual Meeting, and, if necessary, on the following day. Their Report must be submitted to the General Committee on the last day of the Annual Meeting. Procedure.

* Amended by the General Committee at Winnipeg, 1909.

Chapter IV.

Research Committees.

Procedure.

1. Every proposal for special research, or for a grant of money in aid of special research, which is made in any Section, shall be considered by the Committee of that Section; and, if such proposal be approved, it shall be referred to the Committee of Recommendations.

Constitution.

In consequence of any such proposal, a Sectional Committee may recommend the appointment of a Research Committee, composed of Members of the Association, to conduct research or administer a grant in aid of research, and in any case to report thereon to the Association; and the Committee of Recommendations may include such recommendation in their report to the General Committee.

2. Every appointment of a Research Committee shall be proposed at a meeting of the Sectional Committee and adopted at a subsequent meeting. The Sectional Committee shall settle the terms of reference and suitable Members to serve on it, which must be as small as is consistent with its efficient working; and shall nominate a Chairman and a Secretary. Such Research Committee, if appointed, shall have power to add to their numbers.

Proposals by Sectional Committees

3. The Sectional Committee shall state in their recommendation whether a grant of money be desired for the purposes of any Research Committee, and shall estimate the amount required.

All proposals sanctioned by a Sectional Committee shall be forwarded by the Recorder to the Assistant Secretary not later than noon on the Monday of the Annual Meeting for presentation to the Committee of Recommendations.

Tenure

4. Research Committees are appointed for one year only. If the work of a Research Committee cannot be completed in that year, application may be made through a Sectional Committee at the next Annual Meeting for reappointment, with or without a grant—or a further grant—of money.

Reports.

5. Every Research Committee shall present a Report, whether interim or final, at the Annual Meeting next after that at which it was appointed or reappointed. Interim Reports, whether intended for publication or not, must be submitted in writing. Each Sectional Committee shall ascertain whether a Report has been made by each Research Committee

appointed on their recommendation, and shall report to the Committee of Recommendations on or before the Monday of the Annual Meeting.

6. In each Research Committee to which a grant of money has been made, the Chairman is the only person entitled to call on the General Treasurer for such portion of the sum granted as from time to time may be required. GRANTS. (*a*) Drawn by Chairman.

Grants of money sanctioned at the Annual Meeting expire on June 30 following. The General Treasurer is not authorised, after that date, to allow any claims on account of such grants. (*b*) Expire on June 30.

The Chairman of a Research Committee must, before the Annual Meeting next following the appointment of the Research Committee, forward to the General Treasurer a statement of the sums that have been received and expended, together with vouchers. The Chairman must then either return the balance of the grant, if any, which remains unexpended, or, if further expenditure be contemplated, apply for leave to retain the balance. (*c*) Accounts, and balance in hand.

When application is made for a Committee to be reappointed, and to retain the balance of a former grant, and also to receive a further grant, the amount of such further grant is to be estimated as being sufficient, together with the balance proposed to be retained, to make up the amount desired. (*d*) Additional Grants

In making grants of money to Research Committees, the Association does not contemplate the payment of personal expenses to the Members. (*e*) *Caveat.*

A Research Committee, whether or not in receipt of a grant, shall not raise money, in the name or under the auspices of the Association, without special permission from the General Committee.

7. Members and Committees entrusted with sums of money for collecting specimens of any description shall include in their Reports particulars thereof, and shall reserve the specimens thus obtained for disposal, as the Council may direct. Disposal of specimens, apparatus, &c.

Committees are required to furnish a list of any apparatus which may have been purchased out of a grant made by the Association, and to state whether the apparatus is likely to be useful for continuing the research in question or for other specific purposes.

All instruments, drawings, papers, and other property of the Association, when not in actual use by a Committee, shall be deposited at the Office of the Association.

CHAPTER V.

The Council.

Constitution. 1. The Council shall consist of *ex officio* Members and of Ordinary Members elected annually by the General Committee.

(i) The *ex officio* Members are—the Trustees, past Presidents of the Association, the President and Vice-Presidents for the year, the President and Vice-Presidents Elect, past and present General Treasurers and General Secretaries, past Assistant General Secretaries, and the Local Treasurers and Local Secretaries for the ensuing Annual Meeting.

(ii) The Ordinary Members shall not exceed twenty-five in number. Of these, not more than twenty shall have served on the Council as Ordinary Members in the previous year.

Functions. 2. The Council shall have authority to act, in the name and on behalf of the Association, in all matters which do not conflict with the functions of the General Committee.

In the interval between two Annual Meetings, the Council shall manage the affairs of the Association and may fill up vacancies among the General and other Officers, until the next Annual Meeting.

The Council shall hold such meetings as they may think fit, and shall in any case meet on the first day of the Annual Meeting, in order to complete and adopt the Annual Report, and to consider other matters to be brought before the General Committee.

The Council shall nominate for election by the General Committee, at each Annual Meeting, a President and General Officers of the Association.

Suggestions for the Presidency shall be considered by the Council at the Meeting in February, and the names selected shall be issued with the summonses to the Council Meeting in March, when the nomination shall be made from the names on the list.

The Council shall have power to appoint and dismiss such paid officers as may be necessary to carry on the work of the Association, on such terms as they may from time to time determine.

3. Election to the Council shall take place at the same time as that of the Officers of the Association. Elections.

(i) At each Annual Election, the following Ordinary Members of the Council shall be ineligible for re-election in the ensuing year:

(a) Three of the Members who have served for the longest consecutive period, and

(b) Two of the Members who, being resident in or near London, have attended the least number of meetings during the past year.

Nevertheless, it shall be competent for the Council, by an unanimous vote, to reverse the proportion in the order of retirement above set forth.

(ii) The Council shall submit to the General Committee, in their Annual Report, the names of twenty-three Members of the Association whom they recommend for election as Members of Council.

(iii) Two Members shall be elected by the General Committee, without nomination by the Council; and this election shall be at the same meeting as that at which the election of the other Members of the Council takes place.

Any member of the General Committee may propose another member thereof for election as one of these two members of Council, and, if only two are so proposed, they shall be declared elected; but, if more than two are so proposed, the election shall be by show of hands, unless five members at least require it to be by ballot.

Chapter VI.

The President, General Officers, and Staff.

1. The President assumes office on the first day of the Annual Meeting, when he delivers a Presidential Address. He resigns office at the next Annual Meeting, when he inducts his successor into the Chair. The President.

The President shall preside at all meetings of the Association or of its Council and Committees which he attends in his capacity as President. In his absence, he shall be represented by a Vice-President or past President of the Association.

2. The General Officers of the Association are the General Treasurer and the General Secretaries. General Officers.

It shall be competent for the General Officers to act, in the name of the Association, in any matter of urgency which cannot be brought under the consideration of the Council; and they shall report such action to the Council at the next meeting.

The General Treasurer.

3. The General Treasurer shall be responsible to the General Committee and the Council for the financial affairs of the Association.

The General Secretaries.

4. The General Secretaries shall control the general organisation and administration, and shall be responsible to the General Committee and the Council for conducting the correspondence and for the general routine of the work of the Association, excepting that which relates to Finance.

The Assistant Secretary.

5. The Assistant Secretary shall hold office during the pleasure of the Council. He shall act under the direction of the General Secretaries, and in their absence shall represent them. He shall also act on the directions which may be given him by the General Treasurer in that part of his duties which relates to the finances of the Association.

The Assistant Secretary shall be charged, subject as aforesaid: (i) with the general organising and editorial work, and with the administrative business of the Association; (ii) with the control and direction of the Office and of all persons therein employed; and (iii) with the execution of Standing Orders or of the directions given him by the General Officers and Council. He shall act as Secretary, and take Minutes, at the meetings of the Council, and at all meetings of Committees of the Council, of the Committee of Recommendations, and of the General Committee.

Assistant Treasurer.

6. The General Treasurer may depute one of the Staff, as Assistant Treasurer, to carry on, under his direction, the routine work of the duties of his office.

The Assistant Treasurer shall be charged with the issue of Membership Tickets, the payment of Grants, and such other work as may be delegated to him.

Chapter VII.

Finance.

Financial Statements.

1. The General Treasurer, or Assistant Treasurer, shall receive and acknowledge all sums of money paid to the Association. He shall submit, at each meeting of the Council, an *interim* statement of his Account; and, after

June 30 in each year, he shall prepare and submit to the General Committee a balance-sheet of the Funds of the Association.

2. The Accounts of the Association shall be audited, annually, by Auditors appointed by the General Committee. Audit.

3. The General Treasurer shall make all ordinary payments authorised by the General Committee or by the Council. Expenditure.

4. The General Treasurer is empowered to draw on the account of the Association, and to invest on its behalf, part or all of the balance standing at any time to the credit of the Association in the books of the Bank of England, either in Exchequer Bills or in any other temporary investment, and to change, sell, or otherwise deal with such temporary investment as may seem to him desirable. Investments.

5. In the event of the General Treasurer being unable, from illness or any other cause, to exercise the functions of his office, the President of the Association for the time being and one of the General Secretaries shall be jointly empowered to sign cheques on behalf of the Association. Cheques.

CHAPTER VIII.

The Annual Meetings.

1. Local Committees shall be formed to assist the General Officers in making arrangements for the Annual Meeting, and shall have power to add to their number. Local Officers and Committees.

2. The General Committee shall appoint, on the recommendation of the Local Reception or Executive Committee for the ensuing Annual Meeting, a Local Treasurer or Treasurers and two or more Local Secretaries, who shall rank as officers of the Association, and shall consult with the General Officers and the Assistant Secretary as to the local arrangements necessary for the conduct of the meeting. The Local Treasurers shall be empowered to enrol Members and Associates, and to receive subscriptions.

3. The Local Committees and Sub-Committees shall undertake the local organisation, and shall have power to act in the name of the Association in all matters pertaining to the local arrangements for the Annual Meeting other than the work of the Sections. Functions.

CHAPTER IX.

The Work of the Sections.

THE SECTIONS.

1. The scientific work of the Association shall be transacted under such Sections as shall be constituted from time to time by the General Committee.

It shall be competent for any Section, if authorised by the Council for the time being, to form a Sub-Section for the purpose of dealing separately with any group of communications addressed to that Section.

Sectional Officers.

2. There shall be in each Section a President, two or more Vice-Presidents, and two or more Secretaries. They shall be appointed by the Council, for each Annual Meeting in advance, and shall act as the Officers of the Section from the date of their appointment until the appointment of their successors in office for the ensuing Annual Meeting.

Of the Secretaries, one shall act as Recorder of the Section, and one shall be resident in the locality where the Annual Meeting is held.

Rooms.

3. The Section Rooms and the approaches thereto shall not be used for any notices, exhibitions, or other purposes than those of the Association.

SECTIONAL COMMITTEES.

4. The work of each Section shall be conducted by a Sectional Committee, which shall consist of the following :—

Constitution.

(i) The Officers of the Section during their term of office.

(ii) All past Presidents of that Section.

(iii) Such other Members of the Association, present at any Annual Meeting, as the Sectional Committee, thus constituted, may co-opt for the period of the meeting :

Provided always that—

Privilege of Old Members.

(*a*) Any Member of the Association who has served on the Committee of any Section in any previous year, and who has intimated his intention of being present at the Annual Meeting, is eligible as a member of that Committee at their first meeting.

Daily Co-optation.

(*b*) A Sectional Committee may co-opt members, as above set forth, at any time during the Annual Meeting, and shall publish daily a revised list of the members.

(*c*) A Sectional Committee may, at any time during the Annual Meeting, appoint not more than three persons present at the meeting to be Vice-Presidents of the Section, in addition to those previously appointed by the Council. Additional Vice-Presidents.

5. The chief executive officers of a Section shall be the President and the Recorder. They shall have power to act on behalf of the Section in any matter of urgency which cannot be brought before the consideration of the Sectional Committee; and they shall report such action to the Sectional Committee at its next meeting. EXECUTIVE FUNCTIONS

The President (or, in his absence, one of the Vice-Presidents) shall preside at all meetings of the Sectional Committee or of the Section. His ruling shall be absolute on all points of order that may arise. Of President

The Recorder shall be responsible for the punctual transmission to the Assistant Secretary of the daily programme of his Section, of the recommendations adopted by the Sectional Committee, of the printed returns, abstracts, reports, or papers appertaining to the proceedings of his Section at the Annual Meeting, and for the correspondence and minutes of the Sectional Committee. And of Recorder.

6. The Sectional Committee shall nominate, before the close of the Annual Meeting, not more than six of its own members to be members of an Organising Committee, with the officers to be subsequently appointed by the Council, and past Presidents of the Section, from the close of the Annual Meeting until the conclusion of its meeting on the first day of the ensuing Annual Meeting. Organising Committee.

Each Organising Committee shall hold such Meetings as are deemed necessary by its President for the organisation of the ensuing Sectional proceedings, and shall hold a meeting on the first Wednesday of the Annual Meeting: to nominate members of the Sectional Committee, to confirm the Provisional Programme of the Section, and to report to the Sectional Committee.

Each Sectional Committee shall meet daily, unless otherwise determined, during the Annual Meeting: to co-opt members, to complete the arrangements for the next day, and to take into consideration any suggestion for the advancement of Science that may be offered by a member, or may arise out of the proceedings of the Section. Sectional Committee.

No paper shall be read in any Section until it has been accepted by the Sectional Committee and entered as accepted on its Minutes. Papers and Reports.

Any report or paper read in any one Section may be read also in any other Section.

No paper or abstract of a paper shall be printed in the Annual Report of the Association unless the manuscript has been received by the Recorder of the Section before the close of the Annual Meeting.

Recommendations.

It shall be within the competence of the Sectional Committee to review the recommendations adopted at preceding Annual Meetings, as published in the Annual Reports of the Association, and the communications made to the Section at its current meetings, for the purpose of selecting definite objects of research, in the promotion of which individual or concerted action may be usefully employed; and, further, to take into consideration those branches or aspects of knowledge on the state and progress of which reports are required: to make recommendations and nominate individuals or Research Committees to whom the preparation of such reports, or the task of research, may be entrusted, discriminating as to whether, and in what respects, these objects may be usefully advanced by the appropriation of money from the funds of the Association, whether by reference to local authorities, public institutions, or Departments of His Majesty's Government. The appointment of such Research Committees shall be made in accordance with the provisions of Chapter IV.

No proposal arising out of the proceedings of any Section shall be referred to the Committee of Recommendations unless it shall have received the sanction of the Sectional Committee.

Publication.

7. Papers ordered to be printed *in extenso* shall not be included in the Annual Report, if published elsewhere prior to the issue of the Annual Report in volume form. Reports of Research Committees shall not be published elsewhere than in the Annual Report without the express sanction of the Council.

Copyright.

8. The copyright of papers ordered by the General Committee to be printed *in extenso* in the Annual Report shall be vested in the authors; and the copyright of the reports of Research Committees appointed by the General Committee shall be vested in the Association.

Chapter X.

Admission of Members and Associates.

1. No technical qualification shall be required on the part of an applicant for admission as a Member or as an Associate of the British Association; but the Council is empowered, in the event of special circumstances arising, to impose suitable conditions and restrictions in this respect. Applications.

* Every person admitted as a Member or an Associate shall conform to the Rules and Regulations of the Association, any infringement of which on his part may render him liable to exclusion by the Council, who have also authority, if they think it necessary, to withhold from any person the privilege of attending any Annual Meeting or to cancel a ticket of admission already issued. Obligations.

It shall be competent for the General Officers to act, in the name of the Council, on any occasion of urgency which cannot be brought under the consideration of the Council; and they shall report such action to the Council at the next Meeting.

2. All Members are eligible to any office in the Association. Conditions and Privileges of Membership.

(i) Every *Life Member* shall pay, on admission, the sum of Ten Pounds.

Life Members shall receive *gratis* the Annual Reports of the Association.

(ii) Every *Annual Member* shall pay, on admission, the sum of Two Pounds, and in any subsequent year the sum of One Pound.

Annual Members shall receive *gratis* the Report of the Association for the year of their admission and for the years in which they continue to pay, *without intermission*, their annual subscription. An Annual Member who omits to subscribe for any particular year shall lose for that and all future years the privilege of receiving the Annual Reports of the Association *gratis*. He, however, may resume his other privileges as a Member at any subsequent Annual Meeting by paying on each such occasion the sum of One Pound.

(iii) Every *Associate* for a year shall pay, on admission, the sum of One Pound.

* Amended by the General Committee at Dublin, 1908.

Associates shall not receive the Annual Report gratuitously. They shall not be eligible to serve on any Committee, nor be qualified to hold any office in the Association.

(iv) *Ladies* may become Members or Associates on the same terms as gentlemen, or can obtain a *Lady's Ticket* (transferable to ladies only) on the payment of One Pound.

Corresponding Members. 3. Corresponding Members may be appointed by the General Committee, on the nomination of the Council. They shall be entitled to all the privileges of Membership.

Annual Subscriptions. 4. Subscriptions are payable at or before the Annual Meeting. Annual Members not attending the meeting may make payment at any time before the close of the financial year on June 30 of the following year.

The Annual Report. 5. The Annual Report of the Association shall be forwarded *gratis* to individuals and institutions entitled to receive it.

Annual Members whose subscriptions have been intermitted shall be entitled to purchase the Annual Report at two-thirds of the publication price; and Associates for a year shall be entitled to purchase, at the same price, the volume for that year.

Volumes not claimed within two years of the date of publication can only be issued by direction of the Council.

CHAPTER XI.

Corresponding Societies: Conference of Delegates.

Corresponding Societies are constituted as follows

AFFILIATED SOCIETIES. 1. (i) Any Society which undertakes local scientific investigation and publishes the results may become a Society *affiliated* to the British Association.

Each Affiliated Society may appoint a Delegate, who must be or become a Member of the Association and must attend the meetings of the Conference of Delegates. He shall be *ex officio* a Member of the General Committee.

ASSOCIATED SOCIETIES (ii) Any Society formed for the purpose of encouraging the study of Science, which has existed for three years and numbers not fewer than fifty members, may become a Society *associated* with the British Association.

Each Associated Society shall have the right to appoint a Delegate to attend the Annual Conference. Such Delegates must be or become either Members or Associates of the British Association, and shall have all the rights of Delegates appointed by the Affiliated Societies, except that of membership of the General Committee.

2. Application may be made by any Society to be placed on the list of Corresponding Societies. Such application must be addressed to the Assistant Secretary on or before the 1st of June preceding the Annual Meeting at which it is intended it should be considered, and must, in the case of Societies desiring to be affiliated, be accompanied by specimens of the publications of the results of local scientific investigations recently undertaken by the Society. Applications.

3. A Corresponding Societies Committee shall be annually nominated by the Council and appointed by the General Committee, for the purpose of keeping themselves generally informed of the work of the Corresponding Societies and of superintending the preparation of a list of the papers published by the Affiliated Societies. This Committee shall make an Annual Report to the Council, and shall suggest such additions or changes in the list of Corresponding Societies as they may consider desirable. CORRESPONDING SOCIETIES COMMITTEE.

(i) Each Corresponding Society shall forward every year to the Assistant Secretary of the Association, on or before June 1, such particulars in regard to the Society as may be required for the information of the Corresponding Societies Committee. Procedure.

(ii) There shall be inserted in the Annual Report of the Association a list of the papers published by the Corresponding Societies during the preceding twelve months which contain the results of local scientific work conducted by them—those papers only being included which refer to subjects coming under the cognisance of one or other of the several Sections of the Association.

4. The Delegates of Corresponding Societies shall constitute a Conference, of which the Chairman, Vice-Chairman, and Secretary or Secretaries shall be nominated annually by the Council and appointed by the General Committee. The members of the Corresponding Societies Committee shall be *ex officio* members of the Conference. CONFERENCE OF DELEGATES.

(i) The Conference of Delegates shall be summoned by the Secretaries to hold one or more meetings during Procedure and Functions.

each Annual Meeting of the Association, and shall be empowered to invite any Member or Associate to take part in the discussions.

(ii) The Conference of Delegates shall be empowered to submit Resolutions to the Committee of Recommendations for their consideration, and for report to the General Committee.

(iii) The Sectional Committees of the Association shall be requested to transmit to the Secretaries of the Conference of Delegates copies of any recommendations to be made to the General Committee bearing on matters in which the co-operation of Corresponding Societies is desirable. It shall be competent for the Secretaries of the Conference of Delegates to invite the authors of such recommendations to attend the meetings of the Conference in order to give verbal explanations of their objects and of the precise way in which they desire these to be carried into effect.

(iv) It shall be the duty of the Delegates to make themselves familiar with the purport of the several recommendations brought before the Conference, in order that they may be able to bring such recommendations adequately before their respective Societies.

(v) The Conference may also discuss propositions regarding the promotion of more systematic observation and plans of operation, and of greater uniformity in the method of publishing results.

Chapter XII.

Amendments and New Rules.

Alterations.

Any alterations in the Rules, and any amendments or new Rules that may be proposed by the Council or individual Members, shall be notified to the General Committee on the first day of the Annual Meeting, and referred forthwith to the Committee of Recommendations; and, on the report of that Committee, shall be submitted for approval at the last meeting of the General Committee.

Table showing the Places and Dates of Meeting of the British Association, with Presidents, Vice-Presidents, and Local Secretaries, from its Foundation.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
VISCOUNT MILTON, D.C.L., F.R.S., F.G.S., &c. YORK, September 27, 1831.	Rev. W. Vernon Harcourt, M.A., F.R.S., F.G.S.	William Gray, jun., Esq., F.G.S. Professor Phillips, M.A., F.R.S., F.G.S.
The REV. W. BUCKLAND, D.D., F.R.S., F.G.S., &c. OXFORD, June 19, 1832.	Sir David Brewster, F.R.S., F.R.S.E., &c. Rev. W. Whewell, F.R.S., Pres. Geol. Soc.	Professor Daubeny, M.D., F.R.S., &c. Rev. Professor Powell, M.A., F.R.S., &c.
The REV. ADAM SEDGWICK, M.A., V.P.R.S., V.P.G.S. CAMBRIDGE, June 25, 1833.	G. B. Airy, Esq., F.R.S., Astronomer Royal, &c. John Dalton, Esq., D.C.L., F.R.S.	Rev. Professor Henslow, M.A., F.L.S., F.G.S. Rev. W. Whewell, F.R.S.
SIR T. MACDOUGALL BRISBANE, K.C.B., D.C.L., F.R.S., F.R.S.E. EDINBURGH, September 8, 1834.	Sir David Brewster, F.R.S., &c. Rev. T. R. Robinson, D.D.	Professor Forbes, F.R.S., F.R.S.E., &c. Sir John Robinson, Sec. R.S.E.
The REV. PROVOST LLOYD, LL.D. DUBLIN, August 10, 1835.	Viscount Oxmantown, F.R.S., F.R.A.S. Rev. W. Whewell, F.R.S., &c.	Sir W. R. Hamilton, Astronomer Royal of Ireland, &c. Rev. Professor Lloyd, F.R.S.
The MARQUIS OF LANSDOWNE, D.C.L., F.R.S. BRISTOL, August 22, 1836.	The Marquis of Northampton, F.R.S. Rev. W. D. Conybeare, F.R.S., F.G.S. J. C. Prichard, Esq., M.D., F.R.S.	Professor Daubeny, M.D., F.R.S., &c. V. F. Hovenden, Esq.
The EARL OF BURLINGTON, F.R.S., F.G.S., Chancellor of the University of London. LIVERPOOL, September 11, 1837.	The Bishop of Norwich, P.L.S., F.G.S. John Dalton, Esq., D.C.L., F.R.S. Sir Philip de Grey Egerton, Bart., F.R.S., F.G.S. Rev. W. Whewell, F.R.S.	Professor Traill, M.D. Wm. Wallace Currie, Esq. Joseph N. Walker, Esq., Pres. Royal Institution, Liverpool.
The DUKE OF NORTHUMBERLAND, F.R.S., F.G.S., &c. NEWCASTLE-ON-TYNE, August 20, 1838.	The Bishop of Durham, F.R.S., F.S.A. The Rev. W. Vernon Harcourt, F.R.S., &c. Prideaux John Selby, Esq., F.R.S.E.	John Adamson, Esq., F.L.S., &c. Wm. Hutton, Esq., F.G.S. Professor Johnston, M.A., F.R.S.
The REV. W. VERNON HARCOURT, M.A., F.R.S. &c. BIRMINGHAM, August 26, 1839.	The Marquis of Northampton. The Earl of Dartmouth The Rev. T. R. Robinson, D.D. John Corrie, Esq., F.R.S. The Very Rev. Principal Macfarlane	George Barker, Esq., F.R.S. Peyton Blakiston, Esq., M.D. Joseph Hodgson, Esq., F.R.S. Follett Osler, Esq.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
The MARQUIS OF BREADALBANE, F.R.S. GLASGOW, September 17, 1840.	Major-General Lord Greenock, F.R.S.E. Sir David Brewster, F.R.S. Sir T. M. Brisbane, Bart., F.R.S. The Earl of Mount-Edgcumbe	Andrew Liddell, Esq. Rev. J. P. Nicol, LL.D. John Strang, Esq.
The REV. PROFESSOR WHEWELL, F.R.S., &c. PLYMOUTH, July 29, 1841.	The Earl of Morley. Lord Eliot, M.P. Sir C. Lemon, Bart. Sir T. D. Acland, Bart.	W. Snow Harris, Esq., F.R.S. Col. Hamilton Smith, F.L.S. Robert Were Fox, Esq. Richard Taylor, jun., Esq.
The LORD FRANCIS EGERTON, F.G.S. MANCHESTER, June 23, 1842.	John Dalton, Esq., D.C.L., F.R.S. Hon. and Rev. W. Herbert, F.L.S., &c. Rev. A. Sedgwick, M.A., F.R.S. W. C. Henry, Esq., M.D., F.R.S. Sir Benjamin Heywood, Bart.	Peter Clare, Esq., F.R.A.S. W. Fleming, Esq., M.D. James Heywood, Esq., F.R.S.
The EARL OF ROSSE, F.R.S. CORK, August 17, 1843.	The Earl of Listowel. Viscount Adare. Sir W. R. Hamilton, Pres. R.I.A. Rev. T. R. Robinson, D.D.	Professor John Stevelly, M.A. Rev. Jos. Carson, F.T.C. Dublin. William Keleher, Esq. Wm. Clear, Esq.
The REV. G. PEACOCK, D.D. (Dean of Ely), F.R.S. YORK, September 26, 1844.	Earl Fitzwilliam, F.R.S. Viscount Morpeth, F.G.S. The Hon. John Stuart Wortley, M.P. Sir David Brewster, K.H., F.R.S. Michael Faraday, Esq., D.C.L., F.R.S. Rev. W. V. Harcourt, F.R.S.	William Hatfeild, Esq., F.G.S. Thomas Meynell, Esq., F.L.S. Rev. W. Scoresby, LL.D., F.R.S. William West, Esq.
SIR JOHN F. W. HERSCHEL, Bart., F.R.S., &c. CAMBRIDGE, June 19, 1845.	The Earl of Hardwicke. The Bishop of Norwich. Rev. J. Graham, D.D. Rev. G. Ainslie, D.D. G. B. Airy, Esq., M.A., D.C.L., F.R.S. The Rev. Professor Sedgwick, M.A., F.R.S.	William Hopkins, Esq., M.A., F.R.S. Professor Ansted, M.A., F.R.S.
SIR RODERICK IMPEY MURCHISON, G.C.St.S., F.R.S. SOUTHAMPTON, September 10, 1846.	The Marquis of Winchester. The Earl of Yarborough, D.C.L. Lord Ashburton, D.C.L. Viscount Palmerston, M.P. Right Hon. Charles Shaw Lefevre, M.P. Sir George T. Staunton, Bart., M.P., D.C.L., F.R.S. The Lord Bishop of Oxford, F.R.S. Professor Owen, M.D., F.R.S. The Rev. Professor Powell, F.R.S.	Henry Clark, Esq., M.D. T. H. C. Moody, Esq.
SIR ROBERT HARRY INGLIS, Bart., D.C.L., F.R.S., M.P. for the University of Oxford OXFORD, June 23, 1847.	The Earl of Rosse, F.R.S. The Lord Bishop of Oxford, F.R.S. The Vice-Chancellor of the University Thomas G. Bucknall Estcourt, Esq., D.C.L., M.P. for the University of Oxford. The Very Rev. the Dean of Westminster, D.D., F.R.S. Professor Daubeny, M.D., F.R.S. The Rev. Prof. Powell, M.A., F.R.S.	Rev. Robert Walker, M.A., F.R.S. H. Wentworth Acland, Esq., B.M.

The MARQUIS OF NORTHAMPTON, President of the Royal Society, &c. SWANSEA, August 9, 1848.	The Marquis of Bute, K.T. Viscount Adare, F.R.S. Sir H. T. De la Beche, F.R.S., Pres. G.S. The Very Rev. the Dean of Llandaff, F.R.S. Lewis W. Dillwyn, Esq., F.R.S. W. R. Grove, Esq., F.R.S. J. H. Vivian, Esq., M.P., F.R.S. The Lord Bishop of St. David's	Matthew Moggridge, Esq. D. Nicol, Esq., M.D.
The REV. T. R. ROBINSON, D.D., M.R.I.A., F.R.A.S. BIRMINGHAM, September 12, 1849.	The Earl of Harrowby. The Lord Wrottesley, F.R.S. The Right Hon. Sir Robert Peel, Bart., M.P., D.C.L., F.R.S. Charles Darwin, Esq., M.A., F.R.S., Sec. G.S. Professor Faraday, D.C.L., F.R.S. Sir David Brewster, K.H., LL.D., F.R.S. Rev. Prof. Willis, M.A., F.R.S.	Captain Tindal, R.N. William Wills, Esq. Bell Fletcher, Esq., M.D. James Chance, Esq.
SIR DAVID BREWSTER, K.H., LL.D., F.R.S., F.R.S.E., Principal of the United College of St. Salvator and St. Leonard, St. Andrews. EDINBURGH, July 21, 1850.	The Right Hon. the Lord Provost of Edinburgh The Earl of Cathcart, K.C.B., F.R.S.E. The Earl of Rosebery, K.T., D.C.L., F.R.S. The Right Hon. David Boyle (Lord Justice-General), F.R.S.E. General Sir Thomas M. Brisbane, Bart., D.C.L., F.R.S., Pres. R.S.E. The Very Rev. John Lee, D.D., V.P.R.S.E., Principal of the University of Edinburgh. Professor W. P. Alison, M.D., V.P.R.S.E. Professor J. D. Forbes, F.R.S., Sec. R.S.E.	Rev. Professor Kelland, M.A., F.R.S., F.R.S.E. Professor Balfour, M.D., F.R.S.E., F.L.S. James Tod, Esq., F.R.S.E.
GEORGE BIDDELL AIRY, Esq., D.C.L., F.R.S., Astronomer Royal. IPSWICH, July 2, 1851.	The Lord Rendlesham, M.P. The Lord Bishop of Norwich Rev. Professor Sedgwick, M.A., F.R.S. Rev. Professor Henslow, M.A., F.L.S. Sir John P. Boileau, Bart., F.R.S. Sir William F. F. Middleton, Bart. J. C. Cobbold, Esq., M.P. T. B. Western, Esq.	Charles May, Esq., F.R.A.S. Dillwyn Sims, Esq. George Arthur Biddell, Esq. George Ransome, Esq., F.L.S.
COLONEL EDWARD SABINE, Royal Artillery, Treas. & V.P. of the Royal Society. BELFAST, September 1, 1852.	The Earl of Enniskillen, D.C.L., F.R.S. The Earl of Rosse, Pres. R.S., M.R.I.A. Sir Henry T. De la Beche, F.R.S. Rev. Edward Hincks, D.D., M.R.I.A. Rev. P. S. Henry, D.D., Pres. Queen's College, Belfast Rev. T. R. Robinson, D.D., Pres. R.I.A., F.R.A.S. Professor G. G. Stokes, F.R.S. Professor Stevelly, LL.D	W. J. C. Allen, Esq. William M'Gee, Esq., M.D. Professor W. P. Wilson.
WILLIAM HOPKINS, Esq., M.A., V.P.R.S., F.G.S., Pres. Camb. Phil. Society. HULL, September 7, 1853.	The Earl of Carlisle, F.R.S. Lord Londesborough, F.R.S. Professor Faraday, D.C.L., F.R.S. Rev. Prof. Sedgwick, M.A., F.R.S. Charles Frost, Esq., F.S.A., Pres. of the Hull Lit. and Phil. Society William Spence, Esq., F.R.S. Lieut.-Col. Sykes, F.R.S. Professor Wheatstone, F.R.S.	Henry Cooper, Esq., M.D., V.P. Hull Lit. & Phil. Society. Bethel Jacobs, Esq., Pres. Hull Mechanics' Inst.
The EARL OF HARROWBY, F.R.S. LIVERPOOL, September 20, 1854.	The Lord Wrottesley, M.A., F.R.S., F.R.A.S. Sir Philip de Malpas Grey Egerton, Bart., M.P., F.R.S., F.G.S. Professor Owen, M.D., LL.D., F.R.S., F.L.S., F.G.S. Rev. Professor Whewell, D.D., F.R.S., Hon. M.R.I.A., F.G.S., Master of Trinity College, Cambridge William Lassell, Esq., F.R.S., F.R.S.E., F.R.A.S. Joseph Brooks Yates, Esq., F.S.A., F.R.G.S.	Joseph Dickinson, Esq., M.D., F.R.S. Thomas Inman, Esq., M.D.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
The DUKE OF ARGYLL, F.R.S., F.G.S. GLASGOW, September 12, 1855.	The Very Rev. Principal Macfarlane, D.D. Sir William Jardine, Bart., F.R.S.E. Sir Charles Lyell, M.A., LL.D., F.R.S. James Smith, Esq., F.R.S., F.R.S.E. Walter Crum, Esq., F.R.S. Thomas Graham, Esq., M.A., F.R.S., Master of the Royal Mint Professor William Thomson, M.A., F.R.S.	John Strang, Esq., LL.D. Professor Thomas Anderson, M.D. William Gourlie, Esq.
CHARLES G. B. DAUBENY, Esq., M.D., LL.D., F.R.S., Professor of Botany in the University of Oxford CHELTENHAM, August 6, 1856.	The Earl of Ducie, F.R.S., F.G.S. The Lord Bishop of Gloucester and Bristol Sir Roderick I. Murchison, G.C.St.S., D.C.L., F.R.S. Thomas Barwick Lloyd Baker, Esq. The Rev. Francis Close, M.A.	Capt. Robinson, R.A. Richard Beamish, Esq., F.R.S. John West Hugell, Esq.
The REV. HUMPHREY LLOYD, D.D., D.C.L., F.R.S., F.R.S.E., V.P.R.I.A. DUBLIN, August 26, 1857.	The Right Hon. the Lord Mayor of Dublin The Provost of Trinity College, Dublin The Marquis of Kildare. Lord Talbot de Malahide The Lord Chancellor of Ireland The Lord Chief Baron, Dublin Sir William R. Hamilton, LL.D., F.R.A.S., Astronomer Royal of Ireland Lieut.-Colonel Larcom, R.E., LL.D., F.R.S. Richard Griffith, Esq., LL.D., M.R.I.A., F.R.S.E., F.G.S.	Lundy E. Foote, Esq. Rev. Professor Jellett, F.T.C.D. W. Neilson Hancock, Esq., LL.D.
RICHARD OWEN, Esq., M.D., D.C.L., V.P.R.S., F.L.S., F.G.S., Superintendent of the Natural History Departments of the British Museum. LEEDS, September 22, 1858.	The Lord Monteagle, F.R.S. The Lord Viscount Goderich, M.P., F.R.G.S. The Right Hon. M. T. Baines, M.A., M.P. Sir Philip de Malpas Grey Egerton, Bart., M.P., F.R.S., F.G.S. The Rev. W. Whewell, D.D., F.R.S., Hon. M.R.I.A., F.G.S., F.R.A.S., Master of Trinity College, Cambridge James Garth Marshall, Esq., M.A., F.G.S. R. Monckton Milnes, Esq., D.C.L., M.P., F.R.G.S.	Rev. Thomas Hincks, B.A. W. Sykes Ward, Esq., F.C.S. Thomas Wilson, Esq., M.A.
HIS ROYAL HIGHNESS THE PRINCE CONSORT ABERDEEN, September 14, 1859.	The Duke of Richmond, K.G., F.R.S. The Earl of Aberdeen, LL.D., K.G., K.T., F.R.S. The Lord Provost of the City of Aberdeen Sir John F. W. Herschel, Bart., M.A., D.C.L., F.R.S. Sir David Brewster, K.H., D.C.L., F.R.S. Sir Roderick I. Murchison, G.C.St.S., D.C.L., F.R.S. The Rev. W. V. Harcourt, M.A., F.R.S. The Rev. T. R. Robinson, D.D., F.R.S. A. Thomson, Esq., LL.D., F.R.S., Convener of the County of Aberdeen	Professor J. Nicol, F.R.S.E., F.G.S. Professor Fuller, M.A. John F. White, Esq.
The LORD WROTTESLEY, M.A., V.P.R.S., F.R.A.S. OXFORD, June 27, 1860.	The Earl of Derby, K.G., P.C., D.C.L., Chancellor of the Univ. of Oxford The Rev. F. Jeune, D.C.L., Vice-Chancellor of the University of Oxford The Duke of Marlborough, D.C.L., F.G.S., Lord Lieutenant of Oxfordshire The Earl of Rosse, K.P., M.A., F.R.S., F.R.A.S. The Lord Bishop of Oxford, D.D., F.R.S. The Very Rev. H. G. Liddell, D.D., Dean of Christ Church, Oxford Professor Daubeny, M.D., LL.D., F.R.S., F.L.S., F.G.S. Professor Acland, M.D., F.R.S. Professor Donkin, M.A., F.R.S., F.R.A.S.	George Rolleston, Esq., M.D., F.L.S. H. J. S. Smith, Esq., M.A., F.C.S. George Griffith, Esq., M.A., F.C.S.

WILLIAM FAIRBAIRN, Esq., LL.D., C.E., F.R.S. MANCHESTER, September 4, 1861.	The Earl of Ellesmere, F.R.G.S. The Lord Stanley, M.P., D.C.L., F.R.G.S. The Lord Bishop of Manchester, D.D., F.R.S., F.G.S. Sir Philip de Malpas Grey Egerton, Bart., M.P., F.R.S., F.G.S. Sir Benjamin Heywood, Bart., F.R.S. Thomas Bazley, Esq., M.P. James Aspinall Turner, Esq., M.P. James Prescott Joule, Esq., LL.D., F.R.S., Pres. Lit. & Phil. Soc. Manchester Professor E. Hodgkinson, F.R.S., M.R.I.A., M.Inst.C.E. Joseph Whitworth, Esq., F.R.S., M.Inst.C.E.	R. D. Darbishire, Esq., B.A., F.G.S. Alfred Neild, Esq. Arthur Ransome, Esq., M.A. Professor H. E. Roscoe, B.A.
The REV. R. WILLIS, M.A., F.R.S., Jacksonian Professor of Natural and Experimental Philosophy in the University of Cambridge CAMBRIDGE, October 1, 1862.	The Rev. the Vice-Chancellor of the University of Cambridge The Very Rev. Harvey Goodwin, D.D., Dean of Ely The Rev. W. Whewell, D.D., F.R.S., Master of Trinity College, Cambridge The Rev. Professor Sedgwick, M.A., D.C.L., F.R.S. The Rev. J. Challis, M.A., F.R.S. G. B. Airy, Esq., M.A., D.C.L., F.R.S., Astronomer Royal Professor G. G. Stokes, M.A., D.C.L., Sec. R.S. Professor J. C. Adams, M.A., D.C.L., F.R.S., Pres. C.P.S.	Professor C. C. Babington, M.A., F.R.S., F.L.S. Professor G. D. Liveing, M.A. The Rev. N. M. Ferrers, M.A.
[S]IR W. ARMSTRONG, C.B., LL.D., F.R.S. NEWCASTLE-ON-TYNE, August 26, 1863.	Sir Walter C. Trevelyan, Bart., M.A. Sir Charles Lyell, LL.D., D.C.L., F.R.S., F.G.S. Hugh Taylor, Esq., Chairman of the Coal Trade Isaac Lowthian Bell, Esq., Mayor of Newcastle Nicholas Wood, Esq., President of the Northern Institute of Mining Engineers Rev. Temple Chevallier, B.D., F.R.A.S. William Fairbairn, Esq., LL.D., F.R.S.	A. Noble, Esq. Augustus H. Hunt, Esq. R. C. Clapham, Esq.
SIR CHARLES LYELL, Bart., M.A., D.C.L., F.R.S. BATH, September 14, 1864.	The Right Hon. the Earl of Cork and Orrery, Lord-Lieutenant of Somersetshire The Most Noble the Marquis of Bath The Right Hon. Earl Nelson The Right Hon. Lord Portman The Very Rev. the Dean of Hereford The Venerable the Archdeacon of Bath W. Tite, Esq., M.P., F.R.S., F.G.S., F.S.A. A. E. Way, Esq., M.P. Francis H. Dickinson, Esq. W. Sanders, Esq., F.R.S., F.G.S.	C. Moore, Esq., F.G.S. C. E. Davis, Esq. The Rev. H. H. Winwood, M.A.
JOHN PHILLIPS, Esq., M.A., LL.D., F.R.S., F.G.S., Professor of Geology in the University of Oxford BIRMINGHAM, September 6, 1865.	The Right Hon. the Earl of Lichfield, Lord-Lieutenant of Staffordshire The Right Hon. the Earl of Dudley The Right Hon. Lord Leigh, Lord-Lieutenant of Warwickshire The Right Hon. Lord Lyttelton, Lord-Lieutenant of Worcestershire The Right Hon. Lord Wrottesley, M.A., D.C.L., F.R.S., F.R.A.S. The Right Rev. the Lord Bishop of Worcester The Right Hon. C. B. Adderley, M.P. William Scholefield, Esq., M.P. F. Osler, Esq., F.R.S. J. T. Chance, Esq. The Rev. Charles Evans, M.A.	William Mathews, jun., Esq., M.A., F.G.S. John Henry Chamberlain, Esq. The Rev. G. D. Boyle, M.A.

PRESIDENTS.	VICE-PESIDENTS.	LOCAL SECRETARIES.
WILLIAM R. GROVE, Esq., Q.C., M.A., F.R.S. NOTTINGHAM, August 22, 1866.	His Grace the Duke of Devonshire, Lord-Lieutenant of Derbyshire His Grace the Duke of Rutland, Lord-Lieutenant of Leicestershire The Right Hon. Lord Belper, Lord-Lieutenant of Nottinghamshire The Right Hon. J. E. Denison, M.P. J. C. Webb, Esq., High-Sheriff of Nottinghamshire Thomas Graham, Esq., F.R.S., Master of the Mint Joseph Hooker, Esq., M.D., F.R.S., F.L.S. John Russell Hind, Esq., F.R.S., F.R.A.S. T. Close, Esq.	Dr. Robertson. Edward J. Lowe, Esq., F.R.A.S., F.L.S. The Rev. J. F. M'Callan, M.A.
HIS GRACE THE DUKE OF BUCCLEUCH, K.G., D.C.L., F.R.S. DUNDEE, September 4, 1867.	The Right Hon. the Earl of Airlie, K.T. The Right Hon. the Lord Kinnaird, K.T. Sir John Ogilvy, Bart., M.P. Sir Roderick I. Murchison, Bart., K.C.B., LL.D., F.R.S., F.G.S., &c. Sir David Baxter, Bart. Sir David Brewster, D.C.L., F.R.S., Principal of the University of Edinburgh James D. Forbes, Esq., LL.D., F.R.S., Principal of the United College of St. Salvator and St. Leonard, University of St. Andrews	J. Henderson, jun., Esq. John Austin Lake Gloag, Esq. Patrick Anderson, Esq.
JOSEPH DALTON HOOKER, Esq., M.D., D.C.L., F.R.S., F.L.S. NORWICH, August 19, 1868.	The Right Hon. the Earl of Leicester, Lord-Lieutenant of Norfolk Sir John Peter Boileau, Bart., F.R.S. The Rev. Adam Sedgwick, M.A., LL.D., F.R.S., F.G.S., &c., Woodwardian Professor of Geology in the University of Cambridge Sir John Lubbock, Bart., F.R.S., F.L.S., F.G.S. John Couch Adams, Esq., M.A., D.C.L., F.R.S., F.R.A.S., Lowndean Professor of Astronomy and Geometry in the University of Cambridge Thomas Brightwell, Esq.	Dr. Donald Dalrymple. Rev. Joseph Crompton, M.A. Rev. Canon Hinds Howell.
PROFESSOR GEORGE G. STOKES, D.C.L., F.R.S. EXETER, August 18, 1869.	The Right Hon. the Earl of Devon The Right Hon. Sir Stafford H. Northcote, Bart., C.B., M.P., &c. Sir John Bowring, LL.D., F.R.S. William B. Carpenter, Esq., M.D., F.R.S., F.L.S. Robert Were Fox, Esq., F.R.S. W. H. Fox Talbot, Esq., M.A., LL.D., F.R.S., F.L.S.	Henry S. Ellis, Esq., F.R.A.S. John C. Bowring, Esq. The Rev. R. Kirwan.
PROFESSOR T. H. HUXLEY, LL.D., F.R.S., F.G.S. LIVERPOOL, September 14, 1870.	The Right Hon. the Earl of Derby, LL.D., F.R.S. Sir Philip de Malpas Grey Egerton, Bart., M.P. The Right Hon. W. E. Gladstone, D.C.L., M.P. S. R. Graves, Esq., M.P. Sir Joseph Whitworth, Bart., LL.D., D.C.L., F.R.S. James P. Joule, Esq., LL.D., D.C.L., F.R.S. Joseph Mayer, Esq., F.S.A., F.R.G.S.	Rev. W. Banister. Reginald Harrison, Esq. Rev. Henry H. Higgins, M.A. Rev. Dr. A. Hume, F.S.A.

PROFESSOR SIR WILLIAM THOMSON, M.A., LL.D., F.R.S., F.R.S.E. EDINBURGH, August 2, 1871.	His Grace the Duke of Buccleuch, K.G., D.C.L., F.R.S. The Right Hon. the Lord Provost of Edinburgh The Right Hon. John Inglis, LL.D., Lord Justice-General of Scotland. Sir Alexander Grant, Bart., M.A., Principal of the University of Edinburgh Sir Roderick I. Murchison, Bart., K.C.B., G.C.St.S., D.C.L., F.R.S. Sir Charles Lyell, Bart., D.C.L., F.R.S., F.G.S. Dr. Lyon Playfair, C.B., M.P., F.R.S. Professor Christison, M.D., D.C.L., Pres. R.S.E. Professor Balfour, F.R.S., F.R.S.E.	Professor A. Crum Brown, M.D., F.R.S.E. J. D. Marwick, Esq., F.R.S.E.
W. B. CARPENTER, Esq., M.D., LL.D., F.R.S., F.L.S. BRIGHTON, August 14, 1872.	The Right Hon. the Earl of Chichester, Lord-Lieutenant of the County of Sussex. His Grace the Duke of Norfolk His Grace the Duke of Richmond, K.G., P.C., D.C.L. His Grace the Duke of Devonshire, K.G., D.C.L., F.G.S. Sir John Lubbock, Bart., M.P., F.R.S., F.L.S., F.G.S. Dr. Sharpey, LL.D., Sec. R.S., F.L.S. Joseph Prestwich, Esq., F.R.S., Pres. G.S.	Charles Carpenter, Esq. The Rev. Dr. Griffith. Henry Willett, Esq.
PROFESSOR ALEXANDER W. WILLIAMSON, Ph.D., F.R.S., F.C.S. BRADFORD, September 17, 1873.	The Right Hon. the Earl of Rosse, F.R.S., F.R.A.S. The Right Hon. Lord Houghton, D.C.L., F.R.S. The Right Hon. W. E. Forster, M.P. Sir John Hawkshaw, F.R.S., F.G.S. The Mayor of Bradford. Professor Phillips, D.C.L., F.R.S. J. P. Gassiot, Esq., D.C.L., F.R.S.	The Rev. J. R. Campbell, D.D. Richard Goddard, Esq. Peile Thompson, Esq.
PROFESSOR J. TYNDALL, D.C.L., LL.D., F.R.S. BELFAST, August 19, 1874.	The Right Hon. the Earl of Enniskillen, D.C.L., F.R.S. The Right Hon. the Earl of Rosse, F.R.S. Sir Richard Wallace, Bart., M.P. Dr. Andrews, F.R.S. The Rev. Dr. Henry. Professor Stokes, D.C.L., F.R.S. The Rev. Dr. Robinson, F.R.S.	W. Quartus Ewart, Esq. Professor G. Fuller, C.E. T. Sinclair, Esq.
SIR JOHN HAWKSHAW, M.Inst.C.E., F.R.S., F.G.S. BRISTOL, August 25, 1875.	The Right Hon. the Earl of Ducie, F.R.S., F.G.S. The Right Hon. Sir Stafford H. Northcote, Bart., C.B., M.P., F.R.S. The Mayor of Bristol Major-General Sir Henry C. Rawlinson, K.C.B., LL.D., F.R.S., F.R.G.S. Dr. W. B. Carpenter, LL.D., F.R.S., F.L.S., F.G.S. W. Sanders, Esq., F.R.S., F.G.S.	W. Lant Carpenter, Esq., B.A., B.Sc., F.C.S. John H. Clarke, Esq.
PROFESSOR THOMAS ANDREWS, M.D., LL.D., F.R.S., Hon. F.R.S.E. GLASGOW, September 6, 1876.	His Grace the Duke of Argyll, K.T., LL.D., F.R.S., F.R.S.E., F.G.S. The Hon. the Lord Provost of Glasgow Sir William Stirling Maxwell, Bart., M.A., M.P. Professor Sir William Thomson, M.A., LL.D., D.C.L., F.R.S., F.R.S.E. Professor Allen Thomson, M.D., LL.D., F.R.S., F.R.S.E. Professor A. C. Ramsay, LL.D., F.R.S., F.G.S. James Young, Esq., F.R.S., F.C.S.	Dr. W. G. Blackie, F.R.G.S. James Grahame, Esq. J. D. Marwick, Esq.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
PROFESSOR ALLEN THOMSON, M.D., LL.D., F.R.S., F.R.S.E. PLYMOUTH, August 15, 1877.	The Right Hon. the Earl of Mount-Edgcumbe The Right Hon. Lord Blachford, K.C.M.G. William Spottiswoode, Esq., M.A., LL.D., F.R.S., F.R.A.S., F.R.G.S. William Froude, Esq., M.A., C.E., F.R.S. Charles Spence Bate, Esq., F.R.S., F.L.S.	William Adams, Esq. William Square, Esq. Hamilton Whiteford, Esq.
WILLIAM SPOTTISWOODE, Esq., M.A., D.C.L., LL.D., F.R.S., F.R.A.S., F.R.G.S. DUBLIN, August 14, 1878.	The Right Hon. the Lord Mayor of Dublin The Provost of Trinity College, Dublin His Grace the Duke of Abercorn, K.G. The Right Hon. the Earl of Enniskillen, D.C.L., F.R.S., F.G.S. The Right Hon. the Earl of Rosse, B.A., D.C.L., F.R.S., F.R.A.S., M.R.I.A. The Right Hon. Lord O'Hagan, M.R.I.A. Professor G. G. Stokes, M.A., D.C.L., LL.D., Sec. R.S.	Professor R. S. Ball, M.A., F.R.S. James Goff, Esq. John Norwood, Esq., LL.D. Professor G. Sigerson, M.D.
PROFESSOR G. J. ALLMAN, M.D., LL.D., F.R.S., F.R.S.E., M.R.I.A., Pres. L.S. SHEFFIELD, August 20, 1879.	His Grace the Duke of Devonshire, K.G., M.A., LL.D., F.R.S., F.R.G.S. The Right Hon. the Earl Fitzwilliam, K.G., F.R.G.S. The Right Hon. the Earl of Wharncliffe, F.R.G.S. W. H. Brittain, Esq. (Master Cutler) Professor T. H. Huxley, Ph.D., LL.D., Sec. R.S., F.L.S., F.G.S. Professor W. Odling, M.B., F.R.S., F.C.S.	H. Clifton Sorby, Esq., LL.D., F.R.S., F.G.S. J. F. Moss, Esq.
ANDREW CROMBIE RAMSAY, Esq., LL.D., F.R.S., V.P.G.S., Director-General of the Geological Survey of the United Kingdom and of the Museum of Practical Geology. SWANSEA, August 25, 1880.	The Right Hon. the Earl of Jersey The Mayor of Swansea The Hon. Sir W. R. Grove, M.A., D.C.L., F.R.S. H. Hussey Vivian, Esq., M.P., F.G.S. L. Ll. Dillwyn, Esq., M.P., F.L.S., F.G.S. J. Gwyn Jeffreys, Esq., LL.D., F.R.S., F.L.S., Treas. G.S., F.R.G.S.	W. Morgan Esq., Ph.D., F.C.S. James Strick, Esq.
SIR JOHN LUBBOCK, Bart., M.P., D.C.L., LL.D., F.R.S., Pres. L.S., F.G.S. YORK, August 31, 1881.	His Grace the Archbishop of York, D.D., F.R.S. The Right Hon. the Lord Mayor of York The Right Hon. Lord Houghton, D.C.L., F.R.S., F.R.G.S. The Venerable Archdeacon Creyke, M.A. The Hon. Sir W. R. Grove, M.A., D.C.L., F.R.S. Professor G. G. Stokes, M.A., D.C.L., LL.D., Sec. R.S. Sir John Hawkshaw, M.Inst.C.E., F.R.S., F.G.S., F.R.G.S. Allen Thomson, Esq., M.D., LL.D., F.R.S., F.R.S.E. Professor Allman, M.D., LL.D., F.R.S.L., F.R.S.E., F.L.S	Rev. Thomas Adams, M.A. Tempest Anderson, Esq., M.D., B.Sc.
C. W. SIEMENS, Esq., D.C.L., LL.D., F.R.S., F.C.S., M.Inst.C.E. SOUTHAMPTON, August 23, 1882.	The Right Hon. the Lord Mount-Temple Captain Sir F. J. Evans, K.C.B., F.R.S., F.R.A.S., F.R.G.S., Hydrographer to the Admiralty F. A. Abel, Esq., C.B., F.R.S., V.P.C.S., Director of the Chemical Establishment of the War Department Professor De Chaumont, M.D., F.R.S. Major-General A. C. Cooke, R.E., C.B., F.R.G.S., Director-General of the Ordnance Survey. Wyndham S. Portal, Esq. Professor Prestwich, M.A., F.R.S., F.G.S., F.C.S. Philip Lutley Sclater, Esq., M.A., Ph.D., F.R.S., F.L.S., F.G.S.	C. W. A. Jellicoe, Esq. John E. Le Feuvre, Esq. Morris Miles, Esq.

ARTHUR CAYLEY, Esq., M.A., D.C.L., LL.D., F.R.S., V.P.R.A.S., Sadlerian Professor of Pure Mathematics in the University of Cambridge SOUTHPORT, September 19, 1883.	The Right Hon. the Earl of Derby, M.A., LL.D., F.R.S., F.R.G.S. The Right Hon. the Earl of Crawford and Balcarres, LL.D., F.R.S., F.R.A.S. The Right Hon. the Earl of Lathom Principal J. W. Dawson, C.M.G., M.A., LL.D., F.R.S., F.G.S. J. G. Greenwood, Esq., LL.D., Vice-Chancellor of the Victoria University Professor H. E. Roscoe, Ph.D., LL.D., F.R.S., F.C.S.	J. H. Ellis, Esq. Dr. Vernon. T. W. Willis, Esq.
The RIGHT HON. LORD RAYLEIGH, M.A., D.C.L., LL.D., F.R.S., F.R.A.S., F.R.G.S., Professor of Experimental Physics in the University of Cambridge. MONTREAL, August 27, 1884.	His Excellency the Governor-General of Canada, G.C.M.G., LL.D. The Right Hon. Sir John Alexander Macdonald, K.C.B., D.C.L., LL.D. The Right Hon. Sir Lyon Playfair, K.C.B., M.P., LL.D., F.R.S. L. & E. The Hon. Sir Alexander Tilloch Galt, G.C.M.G. The Hon. Sir Charles Tupper, K.C.M.G. Chief Justice Sir A. A. Dorion, C.M.G. Principal Sir William Dawson, C.M.G., M.A., LL.D., F.R.S., F.G.S. The Hon. Dr. Chauveau Professor Edward Frankland, M.D., D.C.L., Ph.D., LL.D., F.R.S., F.C.S. W. H. Hingston, Esq., M.D., D.C.L., L.R.C.S.E. Thomas Sterry Hunt, Esq., M.A., D.Sc., LL.D., F.R.S.	S. E. Dawson, Esq. R. A. Ramsay, Esq. S. Rivard, Esq. S. C. Stevenson, Esq. Thos. White, Esq., M.P.
The RIGHT HON. SIR LYON PLAYFAIR, K.C.B., M.P., Ph.D., LL.D., F.R.S., F.R.S.E., F.C.S. ABERDEEN, September 9, 1885.	His Grace the Duke of Richmond and Gordon, K.G., D.C.L., Chancellor of the University of Aberdeen The Right Hon. the Earl of Aberdeen, LL.D., Lord-Lieutenant of Aberdeenshire The Right Hon. the Earl of Crawford and Balcarres, M.A., LL.D., F.R.S., F.R.A.S. James Matthews, Esq., Lord Provost of the City of Aberdeen Professor Sir William Thomson, M.A., LL.D., F.R.S., F.R.S.E., F.R.A.S. Alexander Bain, Esq., M.A., LL.D., Rector of the University of Aberdeen The Very Rev. Principal Pirie, D.D., Vice-Chancellor of the University of Aberdeen Professor W. H. Flower, LL.D., F.R.S., F.L.S., Pres. Z.S., F.G.S., Director of the Natural History Museum, London Professor John Struthers, M.D., LL.D.	J. W. Crombie, Esq., M.A. Angus Fraser, Esq., M.A., M.D., F.C.S. Professor G. Pirie, M.A.
SIR J. WILLIAM DAWSON, C.M.G., M.A., LL.D., F.R.S., F.G.S., Principal and Vice-Chancellor of McGill University, Montreal, Canada BIRMINGHAM, September 1, 1886.	The Right Hon. the Earl of Bradford, Lord-Lieutenant of Shropshire. The Right Hon. Lord Leigh, D.C.L., Lord-Lieutenant of Warwickshire. The Right Hon. Lord Norton, K.C.M.G. The Right Hon. Lord Wrottesley, Lord-Lieutenant of Staffordshire The Right Rev. the Lord Bishop of Worcester, D.D. Thomas Martineau, Esq., Mayor of Birmingham Professor G. G. Stokes, M.A., D.C.L., LL.D., Pres. R.S. Professor W. A. Tilden, D.Sc., F.R.S., F.C.S. Rev. A. R. Vardy, M.A. Rev. H. W. Watson, D.Sc., F.R.S.	J. Barham Carslake, Esq. Rev. H. W. Crosskey, LL.D., F.G.S. Charles J. Hart, Esq.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
SIR H. E. ROSCOE, M.P., D.C.L., LL.D., Ph.D., F.R.S., V.P.C.S. MANCHESTER, August 31, 1887.	His Grace the Duke of Devonshire, K.G., M.A., LL.D., F.R.S., F.G.S., F.R.G.S. The Right Hon. the Earl of Derby, K.G., M.A., LL.D., F.R.S., F.R.G.S. The Right Rev. the Lord Bishop of Manchester, D.D. The Right Rev. the Bishop of Salford The Right Worshipful the Mayor of Manchester The Right Worshipful the Mayor of Salford The Vice-Chancellor of the Victoria University The Principal of the Owens College Sir William Roberts, B.A., M.D., F.R.S. Thomas Ashton, Esq., J.P., D.L. Oliver Heywood, Esq., J.P., D.L. James Prescott Joule, Esq., D.C.L., LL.D., F.R.S., F.R.S.E., F.C.S.	F. J. Faraday, Esq., F.L.S., F.S.S. Charles Hopkinson, Esq., B.Sc. Professor A. Milnes Marshall, M.A., M.D., D.Sc., F.R.S. Professor A. H. Young, M.B., F.R.C.S.
SIR FREDERICK J. BRAMWELL, D.C.L., F.R.S., M.Inst.C.E. BATH, September 5, 1888.	The Right Hon. the Earl of Cork and Orrery, Lord-Lieutenant of Somerset The Most Hon. the Marquess of Bath The Right Hon. and Right Rev. the Lord Bishop of Bath and Wells, D.D. The Right Rev. the Bishop of Clifton, D.D. The Right Worshipful the Mayor of Bath The Right Worshipful the Mayor of Bristol Sir F. A. Abel, C.B., D.C.L., F.R.S., V.P.C.S. The Venerable the Archdeacon of Bath, M.A. The Rev. Leonard Blomefield, M.A., F.L.S., F.G.S. Professor Michael Foster, M.A., M.D., LL.D., Sec. R.S., F.L.S., F.C.S. W. S. Gore-Langton, Esq., J.P., D.L. H. D. Skrine, Esq., J.P., D.L. E. R. Wodehouse, Esq., M.P. Colonel R. P. Laurie, C.B., M.P. Jerom Murch, Esq., J.P., D.L.	W. Pumphrey, Esq. J. L. Stothert, Esq., M.Inst.C.E. B. H. Watts, Esq.
PROFESSOR WILLIAM HENRY FLOWER, C.B., LL.D., F.R.S., F.R.C.S., Pres. Z.S., F.L.S., F.G.S., Director of the Natural History Departments of the British Museum NEWCASTLE-UPON-TYNE, September 11, 1889.	His Grace the Duke of Northumberland, K.G., D.C.L., LL.D., Lord-Lieutenant of Northumberland The Right Hon. the Earl of Durham, Lord-Lieutenant of Durham The Right Hon. the Earl of Ravensworth The Right Rev. the Lord Bishop of Newcastle, D.D. The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S. The Right Hon. John Morley, M.P., LL.D. The Very Rev. the Warden of the University of Durham, D.D. The Right Worshipful the Mayor of Newcastle The Worshipful the Mayor of Gateshead Sir I. Lowthian Bell, Bart., D.C.L., F.R.S., F.C.S., M.Inst.C.E. Sir Charles Mark Palmer, Bart., M.P.	Professor P. Phillips Bedson, D.Sc., F.C.S. Professor J. Herman Merivale, M.A.

SIR FREDERICK AUGUSTUS ABEL, C.B., D.C.L., D.Sc., F.R.S., F.C.S., Hon.M.Inst.C.E. LEEDS, September 3, 1890.	His Grace the Duke of Devonshire, K.G., M.A., LL.D., F.R.S., F.G.S. The Most Hon. the Marquess of Ripon, K.G., G.C.S.I., C.I.E., F.R.S. The Right Hon. the Earl Fitzwilliam, K.G., F.R.G.S. The Right Rev. the Lord Bishop of Ripon, D.D. The Right Hon. Sir Lyon Playfair, K.C.B., Ph.D., LL.D., M.P., F.R.S. The Right Hon. W. L. Jackson, M.P. Sir James Kitson, Bart., M.Inst.C.E. The Mayor of Leeds Sir Andrew Fairbairn, M.A.	J. Rawlinson Ford, Esq. Sydney Lupton, Esq., M.A. Professor L. C. Miall, F.L.S., F.G.S. Professor A. Smithells, B.Sc.
WILLIAM HUGGINS, Esq., D.C.L., LL.D., Ph.D., F.R.S., F.R.A.S., Hon. F.R.S.E. CARDIFF, August 19, 1891.	The Right Hon. Lord Windsor, Lord-Lieutenant of Glamorganshire The Most Hon. the Marquess of Bute, K.T. The Right Hon. Lord Rayleigh, M.A., D.C.L., LL.D., Sec.R.S., F.R.A.S. The Right Hon. Lord Tredegar The Right Hon. Lord Aberdare, G.C.B., F.R.S., F.R.G.S. Sir J. T. D. Llewelyn, Bart., F.Z.S. Sir Archibald Geikie, LL.D., D.Sc., For.Sec.R.S., F.R.S.E., Pres.G.S. Sir Robert Ball, LL.D., F.R.S., F.R.A.S., Royal Astronomer of Ireland	R. W. Atkinson, Esq., B.Sc., F.C.S., F.I.C. Professor H. W. Lloyd Tanner, M.A., F.R.A.S.
SIR ARCHIBALD GEIKIE, LL.D., D.Sc., For. Sec. R.S., F.R.S.E., F.G.S., Director-General of the Geological Survey of the United Kingdom EDINBURGH, August 3, 1892.	The Right Hon. the Lord Provost of Edinburgh The Most Hon. the Marquess of Lothian, K.T. The Right Hon. the Earl of Rosebery, LL.D., F.R.S., F.R.S.E. The Right Hon. J. H. A. Macdonald, C.B., LL.D., F.R.S., F.R.S.E. Principal Sir William Muir, K.C.S.I., D.C.L. Professor Sir Douglas Maclagan, M.D., Pres.R.S.E. Professor Sir William Turner, F.R.S., F.R.S.E. Professor P. G. Tait, M.A., F.R.S.E. Professor A. Crum Brown, M.D., F.R.S., F.R.S.E., Pres.C.S.	Professor G. F. Armstrong, M.A. M.Inst.C.E., F.R.S.E., F.G.S. F. Grant Ogilvie, Esq., M.A., B.Sc., F.R.S.E. John Harrison, Esq.
DR. J. S. BURDON SANDERSON, M.A., M.D., LL.D., D.C.L., F.R.S., F.R.S.E., Professor of Physiology in the University of Oxford NOTTINGHAM, September 13, 1893.	His Grace the Duke of St. Albans, Lord-Lieutenant of Nottinghamshire His Grace the Duke of Devonshire, K.G., Chancellor of the University of Cambridge His Grace the Duke of Portland His Grace the Duke of Newcastle The Right Hon. Lord Belper The Mayor of Nottingham The Right Hon. Sir W. R. Grove, F.R.S. Sir John Turney, J.P. Professor Michael Foster, M.A., Sec.R.S. W. H. Ransom, Esq., M.D., F.R.S.	Professor F. Clowes, D.Sc. Professor W. H. Heaton, M.A. Arthur Williams, Esq.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
The MOST HON. THE MARQUIS OF SALISBURY, K.G., D.C.L., F.R.S., Chancellor of the University of Oxford. OXFORD, August 8, 1894.	The Right Hon. the Earl of Jersey, G.C.M.G., Lord-Lieutenant of the County of Oxford The Right Hon. Lord Wantage, K.C.B., V.C., Lord-Lieutenant of Berkshire The Right Hon. the Earl of Rosebery, K.G., D.C.L., F.R.S. The Right Rev. the Lord Bishop of Oxford, D.D. The Right Hon. Lord Rothschild, Lord-Lieutenant of Buckinghamshire The Right Hon. Lord Kelvin, D.C.L., Pres.R.S. The Rev. the Vice-Chancellor of the University of Oxford The Mayor of Oxford Sir W. R. Anson, D.C.L., Warden of All Souls College Sir Bernhard Samuelson, Bart., M.P., F.R.S. Sir Henry Dyke Acland, Bart., M.D., F.R.S., Regius Professor of Medicine The Rev. B. Price, D.D., F.R.S., Sedleian Professor of Natural Philosophy Dr. J. J. Sylvester, F.R.S., Savilian Professor of Geometry	Gilbert C. Bourne, Esq., M.A. G. C. Druce, Esq., M.A. D. H. Nagel, Esq., M.A.
CAPTAIN SIR DOUGLAS GALTON, K.C.B., D.C.L., LL.D., F.R.S., F.R.G.S., F.G.S. IPSWICH, September 11, 1895.	The Most Hon. the Marquis of Bristol, M.A., Lord-Lieutenant of the County of Suffolk The Right Hon. Lord Walsingham, LL.D., F.R.S., High Steward of the University of Cambridge The Right Hon. Lord Rayleigh, Sec.R.S., Lord-Lieutenant of Essex The Right Hon. Lord Gwydyr, M.A., High Steward of Ipswich The Right Hon. Lord Henniker, F.S.A. The Right Hon. Lord Rendlesham J. H. Bartlet, Esq., Mayor of Ipswich Sir G. G. Stokes, Bart., D.C.L., F.R.S. Dr. E. Frankland, D.C.L., F.R.S. Professor G. H. Darwin, M.A., F.R.S. Felix T. Cobbold, Esq., M.A.	G. H. Hewetson, Esq. S. A. Notcutt, Esq., B.A., LL.M., B.Sc. E. P. Ridley, Esq.
SIR JOSEPH LISTER, Bart., D.C.L., LL.D., President of the Royal Society. LIVERPOOL, September 16, 1896.	The Right Hon. the Earl of Derby, G.C.B., Lord Mayor of Liverpool. The Right Hon. the Earl of Sefton, K.G., Lord-Lieutenant of Lancashire Sir W. B. Forwood, J.P. Sir Henry E. Roscoe, D.C.L., F.R.S. The Principal of University College, Liverpool W. Rathbone, Esq., LL.D. W. Crookes, Esq., F.R.S., V.P.C.S. T. H. Ismay, Esq., J.P., D.L. Professor A. Liversidge, F.R.S.	Professor W. A. Herdman, F.R.S. Isaac C. Thompson, Esq., F.L.S. W. E. Willink, Esq.
SIR JOHN EVANS, K.C.B., D.C.L., LL.D., Sc.D., Treas.R.S., F.S.A., For. Sec. G. S. TORONTO, August 18, 1897.	His Excellency the Right Hon. the Earl of Aberdeen, G.C.M.G., Governor-General of the Dominion of Canada The Right Hon. Lord Rayleigh, M.A., D.C.L., F.R.S. The Right Hon. Lord Kelvin, G.C.V.O., D.C.L., LL.D., F.R.S., F.R.S.E. The Hon. Sir Wilfrid Laurier, G.C.M.G., Prime Minister of the Dominion of Canada His Honour the Lieutenant-Governor of the Province of Ontario The Hon. the Premier of the Province of Ontario The Hon. the Minister of Education for the Province of Ontario The Hon. Sir Charles Tupper, Bart., G.C.M.G., C.B., LL.D. The Hon. Sir Donald A. Smith, G.C.M.G., LL.D., High Commissioner for Canada Sir William Dawson, C.M.G., F.R.S. The Mayor of Toronto Professor J. Loudon, M.A., LL.D., President of the University of Toronto	Professor A. B. Macallum, M.B., Ph.D. B. E. Walker, Esq., F.G.S. J. S. Willison, Esq.

SIR WILLIAM CROOKES, F.R.S., V.P.C.S. BRISTOL, September 7, 1898.	The Right Hon. the Earl of Ducie, F.R.S., F.G.S. The Right Rev. the Lord Bishop of Bristol, D.D. The Right Hon. Sir Edward Fry, D.C.L., F.R.S., F.S.A. Sir F. J. Bramwell, Bart., D.C.L., LL.D., F.R.S. The Right Worshipful the Mayor of Bristol The Principal of University College, Bristol The Master of the Society of Merchant Venturers of Bristol John Beddoe, Esq., M.D., LL.D., F.R.S. Professor T. G. Bonney, D.Sc., LL.D., F.R.S., F.S.A., F.G.S.	Arthur Lee, Esq., J.P. Bertram Rogers, Esq., M.D.
PROFESSOR SIR MICHAEL FOSTER, K.C.B., M.D., D.C.L., LL.D., Sec. R.S. DOVER, September 13, 1899.	His Grace the Lord Archbishop of Canterbury, D.D. The Most Hon. the Marquis of Salisbury, K.G., M.A., D.C.L., F.R.S. The Mayor of Dover The Major-General Commanding the South-Eastern District The Right Hon. A. Akers-Douglas, M.P. The Very Rev. F. W. Farrar, D.D., F.R.S., Dean of Canterbury Sir J. Norman Lockyer, K.C.B., F.R.S. Professor G. H. Darwin, M.A., LL.D., F.R.S., Pres. R.A.S.	E. Wollaston Knocker, Esq., C.B. W. H. Pendlebury, Esq., M.A.
PROFESSOR SIR WILLIAM TURNER, M.B., D.Sc., D.C.L., LL.D., F.R.S. BRADFORD, September 5, 1900.	The Right Hon. the Earl of Scarbrough, Lord-Lieutenant of the West Riding of Yorkshire His Grace the Duke of Devonshire, K.G., D.C.L., LL.D., F.R.S. The Most Hon. the Marquis of Ripon, K.G., G.C.S.I., D.C.L., F.R.S. The Right Rev. the Lord Bishop of Ripon, D.D. The Right Hon. Lord Masham His Worship the Mayor of Bradford The Hon. H. E. Butler, Lord of the Manor, Bradford Sir Alexander Binnie, M.Inst.C.E., F.G.S. Professor A. W. Rücker, M.A., D.Sc., Sec.R.S. Dr. T. E. Thorpe, Sc.D., F.R.S., Pres.C.S. Principal N. Bodington, Litt.D., Vice-Chancellor of the Victoria University Professor L. C. Miall, F.R.S.	Ramsden Bacchus, Esq. J. E. Fawcett, Esq., J.P. Frederick Stevens, Esq.
PROFESSOR A. W. RÜCKER, M.A., LL.D., D.Sc., Sec R.S. GLASGOW, September 11, 1901.	The Right Hon. the Earl of Glasgow, G.C.M.G. The Right Hon. the Lord Blythswood, LL.D., D.L. The Right Hon. the Lord Kelvin, G.C.V.O., D.C.L., LL.D., F.R.S. Samuel Chisholm, Esq., the Hon. the Lord Provost of Glasgow Very Rev. R. Herbert Story, D.D., LL.D., Principal of the University of Glasgow Sir John Maxwell Stirling-Maxwell, Bart., M.P., D.L. Sir Andrew Noble, K.C.B., D.C.L., F.R.S. Sir Archibald Geikie, D.C.L., LL.D., F.R.S. Sir W. T. Thiselton-Dyer, K.C.M.G., C.I.E., F.R.S. James Parker Smith, Esq., M.P., D.L. John Inglis, Esq., LL.D. Professa John Cleland, M.D., LL.D., D.Sc., F.R.S.	Sir J. D. Marwick, LL.D., D.L., F.R.S.E. Professor John Young, M.D. Professor Magnus Maclean, D.Sc., F.R.S.E.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
PROFESSOR JAMES DEWAR, M.A., LL.D., D.Sc., F.R.S. BELFAST, September 10, 1902.	His Grace the Duke of Abercorn, K.G., H.M. Lieutenant of the County of Donegal The Marquis of Londonderry, K.G., H.M. Lieutenant of the City of Belfast Sir Francis Macnaghten, Bart., H.M. Lieutenant of the County of Antrim The Right Hon. the Earl of Shaftesbury, D.L. The Right Hon. the Earl of Rosse, K.P., D.C.L., LL.D., F.R.S. The Right Hon. Thomas Sinclair, D.Lit. Sir William Quartus Ewart, Bart., M.A. The Lord Mayor of Belfast The President of Queen's College, Belfast Professor E. Ray Lankester, M.A., F.R.S. Professor Peter Redfern, M.D.	John Brown, Esq., F.R.S. Godfrey W. Ferguson, Esq. Professor Maurice FitzGerald, B.A.
SIR NORMAN LOCKYER, K.C.B., LL.D., F.R.S., Correspondant de l'Institut de France SOUTHPORT, September 9, 1903.	The Right Hon. the Earl of Derby, K.G., G.C.B. The Right Hon. the Earl of Crawford and Balcarres, K.T., LL.D., F.R.S. The Right Hon. the Earl Spencer, K.G., LL.D., Chancellor of the Victoria University The Right Hon. the Earl of Sefton The Right Hon. the Earl of Lathom Sir Henry Roscoe, B.A., Ph.D., LL.D., D.C.L., F.R.S. Sir George A. Pilkington Alfred Hopkinson, Esq., LL.D., K.C., Vice-Chancellor of the Victoria University T. T. L. Scarisbrick, Esq., Mayor of Southport E. Marshall Hall, Esq., K.C., M.P. for Southport Charles H. B. Hesketh, Esq. Charles Scarisbrick, Esq., J.P. Charles Weld Blundell, Esq.	Harold Brodrick, Esq., M.A. J. Ernest Jarratt, Esq.
The RIGHT HON. A. J. BALFOUR, D.C.L., LL.D., M.P., F.R.S., Chancellor of the University of Edinburgh CAMBRIDGE, August 17, 1904.	His Grace the Duke of Devonshire, K.G., LL.D., F.R.S., Chancellor of the University of Cambridge Alexander Peckover, Esq., LL.D., Lord Lieutenant of Cambridgeshire Arthur Hall, Esq., M.A., D.L., High Sheriff of Cambridgeshire and Huntingdonshire The Right Rev. the Lord Bishop of Ely, D.D. The Right Hon. Lord Walsingham, LL.D., F.R.S., High Steward of the University of Cambridge The Right Hon. Lord Rayleigh, D.C.L., LL.D., F.R.S. The Right Hon. Lord Kelvin, G.C.V.O., D.C.L., LL.D., F.R.S. The Rev. F. H. Chase, D.D., Vice-Chancellor of the University and President of Queens' College, Cambridge The Very Rev. H. Montagu Butler, D.D., Master of Trinity Mrs. Sidgwick, Principal of Newnham College, Cambridge J. H. Cheshyre Dalton, Esq., M.D., Mayor of Cambridge Robert Stephenson, Esq., Chairman of the Cambridgeshire County Council Joseph Martin, Esq., Chairman of the Isle of Ely County Council P. H. Young, Esq., Deputy Mayor of Cambridge	S. R. Ginn, Esq., D.L. A. Hutchinson, Esq., M.A. A. C. Seward, Esq., M.A., F.R.S. S. Skinner, Esq., M.A. J. E. L. Whitehead, Esq., M.A.

PROFESSOR G. H. DARWIN, M.A., LL.D., Ph.D., F.R.S. SOUTH AFRICA, August 15, 1905.	His Excellency the Right Hon. the Earl of Selborne, G.C.M.G., High Commissioner for South Africa The Right Hon. Lord Milner, G.C.B., G.C.M.G., late High Commissioner for South Africa His Excellency the Hon. Sir Walter F. Hely-Hutchinson, G.C.M.G., Governor of Cape Colony His Excellency Colonel Sir Henry E. McCallum, K.C.M.G., R.E., Governor of Natal His Excellency Captain the Hon. Sir Arthur Lawley, K.C.M.G., Lieutenant-Governor, Transvaal His Excellency Major Sir H. J. Goold-Adams, K.C.M.G., Lieutenant-Governor, Orange River Colony His Honour Sir W. H. Milton, K.C.M.G., Administrator of Southern Rhodesia. Sir Charles H. T. Metcalfe, Bart., M.A. Sir David Gill, K.C.B., LL.D., F.R.S., H.M. Astronomer, Cape Colony Theodore Reunert, M.Inst.C.E. The Mayor of Cape Town The Mayor of Johannesburg The President of the Philosophical Society of South Africa The Mayor of Durban The Mayor of Pietermaritzburg The Mayor of Bloemfontein The Mayor of Pretoria The Mayor of Kimberley The Mayor of Bulawayo	*Cape Town:—* Professor J. C. Beattie, D.Sc., F.R.S.E. E. J. Cattell, J.P. J. R. Finch. Rev. Wm. Flint, D.D. E. Hope Jones. W. L. Sclater, M.A. *Johannesburg:—* W. E. Cursons F. Rowland. *Central Organising Committee for South Africa:—* *Chairman.*—Sir David Gill, K.C.B., F.R.S. *Hon. Secretaries.*—J. D. F. Gilchrist, M.A., Ph.D. (Cape Town); W. Cullen (Johannesburg).
PROFESSOR E. RAY LANKESTER, M.A., LL.D., D.Sc., F.R.S., F.L.S., Director of the Natural History Departments of the British Museum. YORK, August 1, 1906.	His Grace the Archbishop of York, D.D., D.C.L., M.A. The Right Hon. the Lord Mayor of York The High Sheriff of Yorkshire The Most Hon. the Marquess of Ripon, K.G., G.C.S.I., C.I.E., D.C.L., F.R.S. The Right Hon. the Earl of Feversham The Right Rev. the Lord Bishop of Ripon, D.D., D.C.L. The Right Hon. Lord Avebury, D.C.L., LL.D., F.R.S. The Right Hon. Lord Wenlock, G.C.S.I., G.C.I.E., K.C.B. Sir Hugh Bell, Bart. Sir George S. Gibb Tempest Anderson, M.D., D.Sc., President of the Yorkshire Philosophical Society. John Stephenson Rowntree	Henry Craven. C. E. Elmhirst.
SIR DAVID GILL, K.C.B., LL.D., F.R.S., Hon. F.R.S.E. LEICESTER, July 31, 1907.	His Grace the Duke of Rutland, Lord Lieutenant of Leicestershire Richard Dalgliesh, J.P., D.L., High Sheriff of Leicestershire Sir Edward Wood, J.P., Mayor of Leicester The Right Hon. the Earl of Dysart The Right Hon. the Earl Howe, G.C.V.O. The Right Rev. the Lord Bishop of Peterborough, D.D. The Right Rev. the Bishop of Leicester, D.D. Sir Oliver Lodge, D.Sc., LL.D., F.R.S., Principal of the University of Birmingham Herbert Ellis, President of the Leicester Literary and Philosophical Society	Alfred Colson, M.Inst.C.E. E. V. Hiley.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
FRANCIS DARWIN, M.A., M.B., LL.D., F.R.S. DUBLIN, September 2, 1908.	Right Hon. Alderman Gerald O'Reilly, Lord Mayor of Dublin Right Hon. Sir Samuel Walker, Bart., Lord Chancellor of Ireland Right Hon. Augustine Birrell, M.P., Chief Secretary to the Lord Lieutenant of Ireland Right Hon. the Earl of Meath, K.P., His Majesty's Lieutenant for the County of Dublin Right Hon. Lord Castletown of Upper Ossory, K.P., Chancellor of the Royal University of Ireland Anthony Traill, M.D., LL.D., Provost of Trinity College, Dublin Very Rev. William Delany, LL.D., President of University College, Dublin Right Hon. Viscount Iveagh, K.P., LL.D., F.R.S. Right Hon. Lord Ardilaun, D.L., LL.D., President of the Royal Dublin Society Francis A. Tarleton, LL.D., President of the Royal Irish Academy Right Hon. Mr. Justice Madden, M.A., LL.D., Vice-Chancellor of the University of Dublin Sir Christopher Nixon, Bart., M.D., LL.D., Vice-Chancellor of the Royal University of Ireland T. W. Russell, M.P., Vice-President of the Department of Agriculture and Technical Instruction in Ireland	Joseph McGrath, LL.D. John Mulligan, J. P. Professor W. H. Thompson, D.Sc., M.D. Professor W. E. Thrift, M.A.
PROFESSOR SIR J. J. THOMSON, M.A., Sc.D., D.Sc., F.R.S. WINNIPEG, August 25, 1909.	The Right Hon. Lord Strathcona and Mount Royal, G.C.M.G., G.C.V.O., LL.D., High Commissioner in London for the Dominion of Canada The Right Hon. Sir Wilfrid Laurier, G.C.M.G., P.C., D.L., Prime Minister and President of Privy Council The Hon. Sir Daniel Hunter McMillan, K.C.M.G., Lieutenant-Governor of Manitoba The Hon. Rodmond Palen Roblin, Premier of Manitoba The Hon. Amedee E. Forget, Lieutenant-Governor of Saskatchewan The Hon. Walter Scott, Premier of Saskatchewan The Hon. George H. V. Bulyea, Lieutenant-Governor of Alberta The Hon. Alex. C. Rutherford, B.A., LL.D., Premier of Alberta The Hon. James Dunsmuir, Lieutenant-Governor of British Columbia The Hon. Richard McBride, LL.B., K.C., Premier of British Columbia	C. N. Bell. W. Sanford Evans. Professor M. A. Parker, B.Sc., F.C.S. Professor Swale Vincent, M.D., D.Sc.
REV. PROFESSOR T. G. BONNEY, Sc.D., LL.D., F.R.S. SHEFFIELD, August 31, 1910.	Right Hon. the Earl Fitzwilliam, D.S.O., Lord Mayor of Sheffield Herbert Barber, Master Cutler of Sheffield His Grace the Lord Archbishop of York His Grace the Duke of Norfolk, E.M., K.G., G.C.V.O., Litt.D., Chancellor of Sheffield University Right Hon. the Earl of Harewood, K.C.V.O., Lord-Lieutenant of the West Riding of Yorkshire George Franklin, Litt.D., J.P., Pro-Chancellor of Sheffield University Sir Charles Eliot, K.C.M.G., C.B., Vice-Chancellor of Sheffield University Alderman H. K. Stephenson, J.P., Deputy Lord Mayor of Sheffield Right Rev. the Lord Bishop of Sheffield A. J. Hobson, J.P., President of the Sheffield Chamber of Commerce Alderman Sir William Clegg, J.P., Chairman of the Sheffield Education Committee Colonel Herbert Hughes, C.M.G., J.P. Professor W. M. Hicks, Sc.D., F.R.S. Rev. E. H. Titchmarsh, M.A., President of the Sheffield Free Church Council	R. M. Prescott. W. M. Gibbons, M.A.

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1883–95 Sir Douglas Galton, F.R.S., and A. G. Vernon Harcourt, Esq., F.R.S.
1895–97 A. G. Vernon Harcourt, Esq., F.R.S., and Prof. E. A. Schäfer, F.R.S.
1897–1900 Prof. Schäfer, F.R.S., and Sir W. C. Roberts-Austen, F.R.S.
1900–02 Sir W. C. Roberts-Austen, F.R.S., and Dr. D. H. Scott, F.R.S.
1902–03 Dr. D. H. Scott, F.R.S., and Major P. A. MacMahon, F.R.S.
1903– Major P. A. MacMahon, F.R.S., and Prof. W. A. Herdman, F.R.S.

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Date and Place	Presidents	Secretaries
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1833. Cambridge	Sir D. Brewster, F.R.S.	Prof. Forbes.
1834. Edinburgh	Rev. W. Whewell, F.R.S.	Prof. Forbes, Prof. Lloyd.
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1850. Edinburgh	Prof. J. D. Forbes, F.R.S., Sec. R.S.E.	W. J. Macquorn Rankine, Prof. Smyth, Prof. Stevelly, Prof. G. G. Stokes.
1851. Ipswich	Rev. W. Whewell, D.D., F.R.S.	S. Jackson, W. J. Macquorn Rankine, Prof. Stevelly, Prof. G. G. Stokes.
1852. Belfast	Prof. W. Thomson, M.A., F.R.S., F.R.S.E.	Prof. Dixon, W. J. Macquorn Rankine, Prof. Stevelly, J. Tyndall.
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1855. Glasgow	Rev. Prof. Kelland, M.A., F.R.S., F.R.S.E.	Rev. Dr. Forbes, Prof. D. Gray, Prof. Tyndall.
1856. Cheltenham	Rev. R. Walker, M.A., F.R.S.	C. Brooke, Rev. T. A. Southwood, Prof. Stevelly, Rev. J. C. Turnbull.
1857. Dublin	Rev. T. R. Robinson, D.D., F.R.S., M.R.I.A.	Prof. Curtis, Prof. Hennessy, P. A. Ninnis, W. J. Macquorn Rankine, Prof. Stevelly.
1858. Leeds	Rev. W. Whewell, D.D., V.P.R.S.	Rev. S. Earnshaw, J. P. Hennessy, Prof. Stevelly, H. J. S. Smith, Prof. Tyndall.
1859. Aberdeen	The Earl of Rosse, M.A., K.P., F.R.S.	J. P. Hennessy, Prof. Maxwell, H. J. S. Smith, Prof. Stevelly.

Date and Place	Presidents	Secretaries
1860. Oxford......	Rev. B. Price, M.A., F.R.S....	Rev. G. C. Bell, Rev. T. Rennison, Prof. Stevelly.
1861. Manchester	G. B. Airy, M.A., D.C.L., F.R.S.	Prof. R. B Clifton, Prof. H. J. S. Smith, Prof. Stevelly.
1862. Cambridge	Prof. G. G. Stokes, M.A., F.R.S.	Prof. R. B. Clifton, Prof. H. J. S. Smith, Prof. Stevelly.
1863. Newcastle	Prof. W. J. Macquorn Rankine, C.E., F.R.S.	Rev. N. Ferrers, Prof. Fuller, F. Jenkin, Prof. Stevelly, Rev. C. T. Whitley.
1864. Bath.........	Prof. Cayley, M.A., F.R.S., F.R.A.S.	Prof. Fuller, F. Jenkin, Rev. G. Buckle, Prof. Stevelly.
1865. Birmingham	W. Spottiswoode, M.A., F.R.S., F.R.A.S.	Rev. T. N. Hutchinson, F. Jenkin, G. S. Mathews, Prof. H. J. S. Smith, J. M. Wilson.
1866. Nottingham	Prof. Wheatstone, D.C.L., F.R.S.	Fleeming Jenkin, Prof. H. J. S. Smith, Rev. S. N. Swann.
1867. Dundee ...	Prof. Sir W. Thomson, D.C.L., F.R.S.	Rev. G. Buckle, Prof. G. C. Foster, Prof. Fuller, Prof. Swan.
1868. Norwich ...	Prof. J. Tyndall, LL.D., F.R.S.	Prof. G. C. Foster, Rev. R. Harley, R. B. Hayward.
1869. Exeter......	Prof. J. J. Sylvester, LL.D., F.R.S.	Prof. G. C. Foster, R. B. Hayward W. K. Clifford.
1870. Liverpool...	J. Clerk Maxwell, M.A., LL.D., F.R.S.	Prof. W. G. Adams, W. K. Clifford, Prof. G. C. Foster, Rev. W. Allen Whitworth.
1871. Edinburgh	Prof. P. G. Tait, F.R.S.E. ...	Prof. W. G. Adams, J. T. Bottomley, Prof. W. K. Clifford, Prof. J. D. Everett, Rev. R. Harley.
1872. Brighton ...	W. De La Rue, D.C.L., F.R.S.	Prof. W. K. Clifford, J. W. L. Glaisher, Prof. A. S. Herschel, G. F. Rodwell.
1873. Bradford ...	Prof. H. J. S. Smith, F.R.S. .	Prof. W. K. Clifford, Prof. Forbes, J. W. L. Glaisher, Prof. A. S. Herschel.
1874. Belfast......	Rev. Prof. J. H. Jellett, M.A., M.R.I.A.	J. W. L. Glaisher, Prof. Herschel, Randal Nixon, J. Perry, G. F. Rodwell.
1875. Bristol......	Prof. Balfour Stewart, M.A., LL.D., F.R.S.	Prof. W. F. Barrett, J. W. L. Glaisher, C. T. Hudson, G. F. Rodwell.
1876. Glasgow ...	Prof. Sir W. Thomson, M.A., D.C.L., F.R.S.	Prof. W. F. Barrett, J. T. Bottomley, Prof. G. Forbes, J. W. L. Glaisher, T. Muir.
1877. Plymouth...	Prof. G. C. Foster, B.A., F.R.S., Pres. Physical Soc.	Prof. W. F. Barrett, J. T. Bottomley, J. W. L. Glaisher, F. G. Landon.
1878. Dublin......	Rev. Prof. Salmon, D.D., D.C.L., F.R.S.	Prof. J. Casey, G. F. Fitzgerald, J. W. L. Glaisher, Dr. O. J. Lodge.
1879. Sheffield ...	George Johnstone Stoney, M.A., F.R.S.	A. H. Allen, J. W. L. Glaisher, Dr. O. J. Lodge, D. MacAlister.
1880. Swansea ...	Prof. W. Grylls Adams, M.A., F.R.S.	W. E. Ayrton, J. W. L. Glaisher, Dr. O. J. Lodge, D. MacAlister.
1881. York.........	Prof. Sir W. Thomson, M.A., LL.D., D.C.L., F.R.S.	Prof. W. E. Ayrton, Dr. O. J. Lodge, D. MacAlister, Rev. W. Routh.
1882. Southampton.	Rt. Hon. Lord Rayleigh, M.A., F.R.S.	W. M. Hicks, Dr. O. J. Lodge, D. MacAlister, Rev. G. Richardson.
1883. Southport	Prof. O. Henrici, Ph.D., F.R.S.	W. M. Hicks, Prof. O. J. Lodge, D. MacAlister, Prof. R. C. Rowe.
1884. Montreal ...	Prof. Sir W. Thomson, M.A., LL.D., D.C.L., F.R.S.	C. Carpmael, W. M. Hicks, A. Johnson, O. J. Lodge, D. MacAlister.
1885. Aberdeen...	Prof. G. Chrystal, M.A., F.R.S.E.	R. E. Baynes, R. T. Glazebrook, Prof. W. M. Hicks, Prof. W. Ingram.
1886. rmingham	Prof. G. H. Darwin, M.A., LL.D., F.R.S.	R. E. Baynes, R. T. Glazebrook, Prof. J. H. Poynting, W. N. Shaw.

Date and Place	Presidents	Secretaries
1887. Manchester	Prof. Sir R. S. Ball, M.A., LL.D., F.R.S.	R. E. Baynes, R. T. Glazebrook, Prof. H. Lamb, W. N. Shaw.
1888. Bath	Prof. G. F. Fitzgerald, M.A., F.R.S.	R. E. Baynes, R. T. Glazebrook, A. Lodge, W. N. Shaw.
1889. Newcastle-upon-Tyne	Capt. W. de W. Abney, C.B., R.E., F.R.S.	R. E. Baynes, R. T. Glazebrook, A. Lodge, W. N. Shaw, H. Stroud.
1890. Leeds	J. W. L. Glaisher, Sc.D., F.R.S., V.P.R.A.S.	R. T. Glazebrook, Prof. A. Lodge, W. N. Shaw, Prof. W. Stroud.
1891. Cardiff......	Prof. O. J. Lodge, D.Sc., LL.D., F.R.S.	R. E. Baynes, J. Larmor, Prof. A. Lodge, Prof. A. L. Selby.
1892. Edinburgh	Prof. A. Schuster, Ph.D., F.R.S., F.R.A.S.	R. E. Baynes, J. Larmor, Prof. A. Lodge, Dr. W. Peddie.
1893. Nottingham	R. T. Glazebrook, M.A., F.R.S.	W. T. A. Emtage, J. Larmor, Prof. A. Lodge, Dr. W. Peddie.
1894. Oxford	Prof. A. W. Rücker, M.A., F.R.S.	Prof. W. H. Heaton, Prof. A. Lodge, J. Walker.
1895. Ipswich ...	Prof. W. M. Hicks, M.A., F.R.S.	Prof. W. H. Heaton, Prof. A. Lodge, G. T. Walker, W. Watson.
1896. Liverpool...	Prof. J. J. Thomson, M.A., D.Sc., F.R.S.	Prof. W. H. Heaton, J. L. Howard, Prof. A. Lodge, G. T. Walker, W. Watson.
1897. Toronto ...	Prof. A. R. Forsyth, M.A., F.R.S.	Prof. W. H. Heaton, J. C. Glashan, J. L. Howard, Prof. J. C. McLennan.
1898. Bristol	Prof. W. E. Ayrton, F.R.S. ...	A. P. Chattock, J. L. Howard, C. H. Lees, W. Watson, E. T. Whittaker.
1899. Dover	Prof. J. H. Poynting, F.R.S.	J. L. Howard, C. H. Lees, W. Watson, E. T. Whittaker.
1900. Bradford ...	Dr. J. Larmor, F.R.S.—*Dep. of Astronomy*, Dr. A. A. Common, F.R.S.	P. H. Cowell, A. Fowler, C. H. Lees, C. J. L. Wagstaffe, W. Watson, E. T. Whittaker.
1901. Glasgow ...	Major P. A. MacMahon, F.R.S. —*Dep. of Astronomy*, Prof. H. H. Turner, F.R.S.	H. S. Carslaw, C. H. Lees, W. Stewart, Prof. L. R. Wilberforce.
1902. Belfast......	Prof. J. Purser, LL.D., M.R.I.A. —*Dep. of Astronomy*, Prof. A. Schuster, F.R.S.	H. S. Carslaw, A. R. Hinks, A. Larmor, C. H. Lees, Prof. W. B. Morton, A. W. Porter.
1903. Southport	C. Vernon Boys, F.R.S.—*Dep. of Astronomy and Meteorology*, Dr. W. N. Shaw, F.R.S	D. E. Benson, A. R. Hinks, R. W. H. T. Hudson, Dr. C. H. Lees, J. Loton, A. W. Porter.
1904. Cambridge	Prof. H. Lamb, F.R.S.—*Sub-Section of Astronomy and Cosmical Physics*, Sir J. Eliot, K.C.I.E., F.R.S.	A. R. Hinks, R. W. H. T. Hudson, Dr. C. H. Lees, Dr. W. J. S. Lockyer, A. W. Porter, W. C. D. Whetham.
1905. SouthAfrica	Prof. A. R. Forsyth, M.A., F.R.S.	A. R. Hinks, S. S. Hough, R. T. A. Innes, J. H. Jeans, Dr. C. H. Lees.
1906. York.........	Principal E. H. Griffiths, F.R.S.	Dr. L. N. G. Filon, Dr. J. A. Harker, A. R. Hinks, Prof. A. W. Porter, H. Dennis Taylor.
1907. Leicester ...	Prof. A. E. H. Love, M.A., F.R S.	E. E. Brooks, Dr. L. N. G. Filon, Dr. J. A. Harker, A. R. Hinks, Prof. A. W. Porter.
1908. Dublin	Dr. W. N. Shaw, F.R.S.	Dr. W. G. Duffield, Dr. L. N. G. Filon, E. Gold, Prof. J. A. McClelland, Prof. A. W. Porter, Prof. E. T. Whittaker.
1909. Winnipeg	Prof. E. Rutherford, F.R.S.	Prof. F. Allen, Prof. J. C. Fields, E. Gold, F. Horton, Prof. A. W. Porter, Dr. A. A. Rambaut.
1910. Sheffield ...	Prof. E. W. Hobson, F.R.S....	H. Bateman, A. S. Eddington, E. Gold, Dr. F. Horton, Dr. S. R. Milner, Prof. A. W. Porter.

Date and Place	Presidents	Secretaries

CHEMICAL SCIENCE.

COMMITTEE OF SCIENCES, II.—CHEMISTRY, MINERALOGY, &c.

1832. Oxford	John Dalton, D.C.L., F.R.S.	James F. W. Johnston.
1833. Cambridge	John Dalton, D.C.L., F.R.S.	Prof. Miller.
1834. Edinburgh	Dr. Hope	Mr. Johnston, Dr. Christison.

SECTION B.—CHEMISTRY AND MINERALOGY.

1835. Dublin	Dr. T. Thomson, F.R.S.	Dr. Apjohn, Prof. Johnston.
1836. Bristol	Rev. Prof. Cumming	Dr. Apjohn, Dr. C. Henry, W. Herapath.
1837. Liverpool	Michael Faraday, F.R.S.	Prof. Johnston, Prof. Miller, Dr. Reynolds.
1838. Newcastle	Rev. William Whewell, F.R.S.	Prof. Miller, H. L. Pattinson, Thomas Richardson.
1839. Birmingham	Prof. T. Graham, F.R.S.	Dr. Golding Bird, Dr. J. B. Melson.
1840. Glasgow	Dr. Thomas Thomson, F.R.S.	Dr. R. D. Thomson, Dr. T. Clark, Dr. L. Playfair.
1841. Plymouth	Dr. Daubeny, F.R.S.	J. Prideaux, R. Hunt, W. M. Tweedy.
1842. Manchester	John Dalton, D.C.L., F.R.S.	Dr. L. Playfair, R. Hunt, J. Graham.
1843. Cork	Prof. Apjohn, M.R.I.A.	R. Hunt, Dr. Sweeny.
1844. York	Prof. T. Graham, F.R.S.	Dr. L. Playfair, E. Solly, T. H. Barker.
1845. Cambridge	Rev. Prof. Cumming	R. Hunt, J. P. Joule, Prof. Miller, E. Solly.
1846. Southampton.	Michael Faraday, D.C.L., F.R.S.	Dr. Miller, R. Hunt, W. Randall.
1847. Oxford	Rev. W. V. Harcourt, M.A., F.R.S.	B. C. Brodie, R. Hunt, Prof. Solly.
1848. Swansea	Richard Phillips, F.R.S.	T. H. Henry, R. Hunt, T. Williams.
1849. Birmingham	John Percy, M.D., F.R.S.	R. Hunt, G. Shaw.
1850. Edinburgh	Dr. Christison, V.P.R.S.E.	Dr. Anderson, R. Hunt, Dr. Wilson.
1851. Ipswich	Prof. Thomas Graham, F.R.S.	T. J. Pearsall, W. S. Ward.
1852. Belfast	Thomas Andrews, M.D., F.R.S.	Dr. Gladstone, Prof. Hodges, Prof. Ronalds.
1853. Hull	Prof. J. F. W. Johnston, M.A., F.R.S.	H. S. Blundell, Prof. R. Hunt, T. J. Pearsall.
1854. Liverpool	Prof. W. A. Miller, M.D., F.R.S.	Dr. Edwards, Dr. Gladstone, Dr. Price.
1855. Glasgow	Dr. Lyon Playfair, C.B., F.R.S.	Prof. Frankland, Dr. H. E. Roscoe.
1856. Cheltenham	Prof. B. C. Brodie, F.R.S.	J. Horsley, P. J. Worsley, Prof. Voelcker.
1857. Dublin	Prof. Apjohn, M.D., F.R.S., M.R.I.A.	Dr. Davy, Dr. Gladstone, Prof. Sullivan.
1858. Leeds	Sir J. F. W. Herschel, Bart., D.C.L.	Dr. Gladstone, W. Odling, R. Reynolds.
1859. Aberdeen	Dr. Lyon Playfair, C.B., F.R.S.	J. S. Brazier, Dr. Gladstone, G. D. Liveing, Dr. Odling.
1860. Oxford	Prof. B. C. Brodie, F.R.S.	A. Vernon Harcourt, G. D. Liveing, A. B. Northcote.
1861. Manchester	Prof. W. A. Miller, M.D., F.R.S.	A. Vernon Harcourt, G. D. Liveing.
1862. Cambridge	Prof. W. H. Miller, M.A., F.R.S.	H. W. Elphinstone, W. Odling, Prof. Roscoe.
1863. Newcastle	Dr. Alex. W. Williamson, F.R.S.	Prof. Liveing, H. L. Pattinson, J. C. Stevenson.
1864. Bath	W. Odling, M.B., F.R.S.	A. V. Harcourt, Prof. Liveing, R. Biggs.

Date and Place	Presidents	Secretaries
1865. Birmingham	Prof. W. A. Miller, M.D., V.P.R.S.	A. V. Harcourt, H. Adkins, Prof. Wanklyn, A. Winkler Wills.
1866. Nottingham	H. Bence Jones, M.D., F.R.S.	J. H. Atherton, Prof. Liveing, W. J. Russell, J. White.
1867. Dundee ...	Prof. T. Anderson, M.D., F.R.S.E.	A. Crum Brown, Prof. G. D. Liveing, W. J. Russell.
1868. Norwich ...	Prof. E. Frankland, F.R.S.	Dr. A. Crum Brown, Dr. W. J. Russell, F. Sutton.
1869. Exeter	Dr. H. Debus, F.R.S.	Prof. A. Crum Brown, Dr. W. J. Russell, Dr. Atkinson.
1870. Liverpool...	Prof. H. E. Roscoe, B.A., F.R.S.	Prof. A. Crum Brown, A. E. Fletcher, Dr. W. J. Russell.
1871. Edinburgh	Prof. T. Andrews, M.D., F.R.S.	J. Y. Buchanan, W. N. Hartley, T. E. Thorpe.
1872. Brighton ...	Dr. J. H. Gladstone, F.R.S....	Dr. Mills, W. Chandler Roberts, Dr. W. J. Russell, Dr. T. Wood.
1873. Bradford ...	Prof. W. J. Russell, F.R.S....	Dr. Armstrong, Dr. Mills, W. Chandler Roberts, Dr. Thorpe.
1874. Belfast......	Prof. A. Crum Brown, M.D., F.R.S.E.	Dr. T. Cranstoun Charles, W. Chandler Roberts, Prof. Thorpe.
1875. Bristol	A. G. Vernon Harcourt, M.A., F.R.S.	Dr. H. E. Armstrong, W. Chandler Roberts, W. A. Tilden.
1876. Glasgow ...	W. H. Perkin, F.R.S.	W. Dittmar, W. Chandler Roberts, J. M. Thomson, W. A. Tilden.
1877. Plymouth...	F. A. Abel, F.R.S...............	Dr. Oxland, W. Chandler Roberts, J. M. Thomson.
1878. Dublin	Prof. Maxwell Simpson, M.D., F.R.S.	W. Chandler Roberts, J. M. Thomson, Dr. C. R. Tichborne, T. Wills.
1879. Sheffield ...	Prof. Dewar, M.A., F.R.S. ...	H. S. Bell, W. Chandler Roberts, J. M. Thomson.
1880. Swansea ...	Joseph Henry Gilbert, Ph.D., F.R.S.	P. P. Bedson, H. B. Dixon, W. R. E. Hodgkinson, J. M. Thomson.
1881. York.........	Prof. A. W. Williamson, F.R.S.	P. P. Bedson, H. B. Dixon, T. Gough.
1882. Southampton.	Prof. G. D. Liveing, M.A., F.R.S.	P. Phillips Bedson, H. B. Dixon, J. L. Notter.
1883. Southport	Dr. J. H. Gladstone, F.R.S...	Prof. P. Phillips Bedson, H. B. Dixon, H. Forster Morley.
1884. Montreal ...	Prof. Sir H. E Roscoe, Ph.D., LL.D., F.R.S.	Prof. P. Phillips Bedson, H. B. Dixon, T. McFarlane, Prof. W. H. Pike.
1885. Aberdeen ...	Prof. H. E. Armstrong, Ph.D., F.R.S., Sec. C.S.	Prof. P. Phillips Bedson, H. B. Dixon, H. Forster Morley, Dr. W. J. Simpson.
1886. Birmingham	W. Crookes, F.R.S., V.P.C.S.	P. P. Bedson, H. B. Dixon, H. F. Morley, W. W. J. Nicol, C. J. Woodward.
1887. Manchester	Dr. E. Schunck, F.R.S.	Prof. P. Phillips Bedson, H. Forster Morley, W. Thomson.
1888. Bath.........	Prof. W. A. Tilden, D.Sc., F.R.S., V.P.C.S.	Prof. H. B. Dixon, H. Forster Morley, R. E. Moyle, W. W. J. Nicol.
1889. Newcastle-upon-Tyne	Sir I. Lowthian Bell, Bart., D.C.L., F.R.S.	H. Forster Morley, D. H. Nagel, W. W. J. Nicol, H. L. Pattinson, jun.
1890. Leeds	Prof. T. E. Thorpe, B.Sc., Ph.D., F.R.S., Treas. C.S.	C. H. Bothamley, H. Forster Morley, D. H. Nagel, W. W. J. Nicol.
1891. Cardiff	Prof. W. C. Roberts-Austen, C.B., F.R.S.	C. H. Bothamley, H. Forster Morley, W. W. J. Nicol, G. S. Turpin.
1892. Edinburgh	Prof. H. McLeod, F.R.S.......	J. Gibson, H. Forster Morley, D. H. Nagel, W. W. J. Nicol.
1893. Nottingham	Prof. J. Emerson Reynolds, M.D., D.Sc., F.R.S.	J. B. Coleman, M. J. R. Dunstan, D. H. Nagel, W. W. J. Nicol.
1894. Oxford	Prof. H. B. Dixon, M.A., F.R.S.	A. Colefax, W. W. Fisher, Arthur Harden, H. Forster Morley.

Date and Place	Presidents	Secretaries
	SECTION B (*continued*).—CHEMISTRY.	
1895. Ipswich ...	Prof. R. Meldola, F.R.S.	E. H. Fison, Arthur Harden, C. A Kohn, J. W. Rodger.
1896. Liverpool...	Dr. Ludwig Mond, F.R.S. ...	Arthur Harden, C. A. Kohn.
1897. Toronto ...	Prof. W. Ramsay, F.R.S.......	Prof. W. H. Ellis, A. Harden, C. A. Kohn, Prof. R. F. Ruttan.
1898. Bristol......	Prof. F. R. Japp, F.R.S.	C. A. Kohn, F. W. Stoddart, T. K. Rose.
1899. Dover	Horace T. Brown, F.R.S.......	A. D. Hall, C. A. Kohn, T. K. Rose, Prof. W. P. Wynne.
1900. Bradford ...	Prof. W. H. Perkin, F.R.S. ...	W. M. Gardner, F. S. Kipping, W. J. Pope, T. K. Rose.
1901. Glasgow ...	Prof. Percy F. Frankland, F.R.S.	W. C. Anderson, G. G. Henderson, W. J. Pope, T. K. Rose.
1902. Belfast......	Prof. E. Divers, F.R.S..........	R. F. Blake, M. O. Forster, Prof. G. G. Henderson, Prof. W. J. Pope.
1903. Southport	Prof. W. N. Hartley, D.Sc., F.R.S.	Dr. M. O. Forster, Prof. G. G. Henderson, J. Ohm, Prof. W. J. Pope.
1904. Cambridge	Prof. Sydney Young, F.R.S....	Dr. M. O. Forster, Prof. G. G. Henderson, Dr. H. O. Jones, Prof. W. J. Pope.
1905. South Africa	George T. Beilby	W. A. Caldecott, Dr. M. O. Forster, Prof. G. G. Henderson, C. F. Juritz.
1906. York.........	Prof. Wyndham R. Dunstan, F.R.S.	Dr. E. F. Armstrong, Prof. A. W. Crossley, S. H. Davies, Prof. W. J. Pope.
1907. Leicester ...	Prof. A. Smithells, F.R.S. ...	Dr. E. F. Armstrong, Prof. A. W. Crossley, J. H. Hawthorn, Dr. F. M. Perkin.
1908. Dublin	Prof. F. S. Kipping, F.R.S. ...	Dr. E. F. Armstrong, Dr. A. McKenzie, Dr. F. M. Perkin, Dr. J. H. Pollock.
1909. Winnipeg...	Prof. H. E. Armstrong, F.R.S.	Dr. E. F. Armstrong, Dr. T. M. Lowry, Dr. F. M. Perkin, J. W. Shipley.
1910. Sheffield ...	J. E. Stead, F.R.S............	Dr. E. F. Armstrong, Dr. T. M. Lowry, Dr. F. M. Perkin, W. E. S. Turner.
	Sub-section of Agriculture, A. D. Hall, F.R.S.	Dr. C. Crowther, J. Golding, Dr. E. J. Russell.

GEOLOGICAL (AND, UNTIL 1851, GEOGRAPHICAL) SCIENCE.

Date and Place	Presidents	Secretaries
	COMMITTEE OF SCIENCES, III.—GEOLOGY AND GEOGRAPHY.	
1832. Oxford	R. I. Murchison, F.R.S.	John Taylor.
1833. Cambridge	G. B. Greenough, F.R.S.	W. Lonsdale, John Phillips.
1834. Edinburgh	Prof. Jameson	J. Phillips, T. J. Torrie, Rev. J. Yates.
	SECTION C.—GEOLOGY AND GEOGRAPHY.	
1835. Dublin	R. J. Griffith	Captain Portlock, T. J. Torrie.
1836. Bristol	Rev. Dr. Buckland, F.R.S.—*Geog.*, R. I. Murchison, F.R.S.	William Sanders, S. Stutchbury, T. J. Torrie.
1837. Liverpool...	Rev. Prof. Sedgwick, F.R.S.—*Geog.*, G. B. Greenough, F.R.S.	Captain Portlock, R. Hunter.—*Geography*, Capt. H. M. Denham, R.N.
1838. Newcastle..	C. Lyell, F.R.S., V.P.G.S.—*Geography*, Lord Prudhoe.	W. C. Trevelyan, Capt. Portlock.—*Geography*, Capt. Washington.
1839. Birmingham	Rev. Dr. Buckland, F.R.S.—*Geog.*, G. B. Greenough, F.R.S.	George Lloyd, M.D., H. E. Strickland, Charles Darwin.
1840. Glasgow ...	Charles Lyell, F.R.S.—*Geog.*, G. B. Greenough, F.R.S.	W. J. Hamilton, D. Milne, H. Murray, H. E. Strickland, J. Scoular.
1841. Plymouth...	H. T. De la Beche, F.R.S. ...	W. J. Hamilton, Edward Moore, M.D., R. Hutton.
1842. Manchester	R. I. Murchison, F.R.S.	E. W. Binney, R. Hutton, Dr. R. Lloyd, H. E. Strickland.

Date and Place	Presidents	Secretaries
1843. Cork	Richard E. Griffith, F.R.S. ...	F. M. Jennings, H. E. Strickland.
1844. York.........	Henry Warburton, Pres. G. S.	Prof. Ansted, E. H. Bunbury.
1845. Cambridge	Rev. Prof. Sedgwick, M.A. F.R.S.	Rev. J. C. Cumming, A. C. Ramsay, Rev. W. Thorp.
1846. Southampton.	Leonard Horner, F.R.S.	Robert A. Austen, Dr. J. H. Norton, Prof. Oldham, Dr. C. T. Beke.
1847. Oxford......	Very Rev.Dr.Buckland,F.R.S.	Prof. Ansted, Prof. Oldham, A. C. Ramsay, J. Ruskin.
1848. Swansea ...	Sir H. T. De la Beche, F.R.S.	S.Benson,Prof.Oldham,Prof.Ramsay
1849. Birmingham	Sir Charles Lyell, F.R.S.......	J. B. Jukes, Prof. Oldham, A. C. Ramsay.
1850. Edinburgh[1]	Sir Roderick I. Murchison, F.R.S.	A. Keith Johnston, Hugh Miller, Prof. Nicol.

SECTION C (*continued*).—GEOLOGY.

Date and Place	Presidents	Secretaries
1851. Ipswich ...	William Hopkins, M.A., F.R.S.	C. J. F. Bunbury, G. W. Ormerod, Searles Wood.
1852. Belfast......	Lieut.-Col. Portlock, R.E., F.R.S.	James Bryce, James MacAdam, Prof. M'Coy, Prof. Nicol.
1853. Hull	Prof. Sedgwick, F.R.S.........	Prof. Harkness, William Lawton.
1854. Liverpool...	Prof. Edward Forbes, F.R.S.	John Cunningham, Prof. Harkness, G. W. Ormerod, J. W. Woodall.
1855. Glasgow ...	Sir R. I. Murchison, F.R.S....	J. Bryce, Prof. Harkness, Prof. Nicol.
1856. Cheltenham	Prof. A. C. Ramsay, F.R.S....	Rev. P. B. Brodie, Rev. R. Hepworth, Edward Hull, J. Scougall, T. Wright.
1857. Dublin	The Lord Talbot de Malahide	Prof. Harkness, G. Sanders, R. H. Scott.
1858. Leeds	William Hopkins, M.A., F.R.S.	Prof. Nicol, H. C. Sorby, E. W. Shaw.
1859. Aberdeen...	Sir Charles Lyell, LL.D., D.C.L., F.R.S.	Prof. Harkness, Rev. J. Longmuir, H. C. Sorby.
1860. Oxford	Rev. Prof. Sedgwick, F.R.S...	Prof. Harkness, E. Hull, J. W. Woodall.
1861. Manchester	Sir R. I. Murchison, D.C.L., LL.D., F.R.S.	Prof. Harkness, Edward Hull, T. Rupert Jones, G. W. Ormerod.
1862. Cambridge	J. Beete Jukes, M.A., F.R.S.	Lucas Barrett, Prof. T. Rupert Jones, H. C. Sorby.
1863. Newcastle	Prof. Warington W. Smyth, F.R.S., F.G.S.	E. F. Boyd, John Daglish, H. C. Sorby, Thomas Sopwith.
1864. Bath	Prof. J. Phillips, LL.D., F.R.S., F.G.S.	W. B. Dawkins, J. Johnston, H. C. Sorby, W. Pengelly.
1865. Birmingham	Sir R. I. Murchison, Bart., K.C.B., F.R.S.	Rev. P. B. Brodie, J. Jones, Rev. E. Myers, H. C. Sorby, W. Pengelly.
1866. Nottingham	Prof. A. C. Ramsay, LL.D., F.R.S.	R. Etheridge, W. Pengelly, T. Wilson, G. H. Wright.
1867. Dundee ...	Archibald Geikie, F.R.S.......	E. Hull, W. Pengelly, H. Woodward.
1868. Norwich ...	R. A. C. Godwin-Austen, F.R.S., F.G.S.	Rev. O. Fisher, Rev. J. Gunn, W. Pengelly, Rev. H. H. Winwood.
1869. Exeter	Prof. R. Harkness, F.R.S., F.G.S.	W. Pengelly, W. Boyd Dawkins Rev. H. H. Winwood.
870. Liverpool...	Sir Philip de M. Grey Egerton, Bart., M.P., F.R.S.	W. Pengelly, Rev. H. H. Winwood, W. Boyd Dawkins, G. H. Morton.
1871. Edinburgh	Prof. A. Geikie, F.R.S., F.G.S.	R. Etheridge, J. Geikie, T. McKenny Hughes, L. C. Miall.
1872. Brighton...	R. A. C. Godwin-Austen, F.R.S., F.G.S.	L. C. Miall, George Scott, William Topley, Henry Woodward.
1873. Bradford ...	Prof. J. Phillips, F.R.S.	L.C.Miall, R.H.Tiddeman, W.Topley

[1] Geography was constituted a separate Section, see page lxxix.

Date and Place	Presidents	Secretaries
1874. Belfast......	Prof. Hull, M.A., F.R.S., F.G.S.	F. Drew, L. C. Miall, R. G. Symes, R. H. Tiddeman.
1875. Bristol......	Dr. T. Wright, F.R.S.E., F.G.S.	L. C. Miall, E. B. Tawney, W. Topley.
1876. Glasgow ...	Prof. John Young, M.D.	J. Armstrong, F. W. Rudler, W. Topley.
1877. Plymouth...	W. Pengelly, F.R.S., F.G.S.	Dr. Le Neve Foster, R. H. Tiddeman, W. Topley.
1878. Dublin......	John Evans, D.C.L., F.R.S. F.S.A., F.G.S.	E. T. Hardman, Prof. J. O'Reilly, R. H. Tiddeman.
1879. Sheffield ...	Prof. P. M. Duncan, F.R.S.	W. Topley, G. Blake Walker.
1880. Swansea ...	H. C. Sorby, F.R.S., F.G.S....	W. Topley, W. Whitaker.
1881. York.........	A. C. Ramsay, LL.D., F.R.S., F.G.S.	J. E. Clark, W. Keeping, W. Topley, W. Whitaker.
1882. Southampton.	R. Etheridge, F.R.S., F.G.S.	T. W. Shore, W. Topley, E. Westlake, W. Whitaker.
1883. Southport	Prof. W. C. Williamson, LL.D., F.R.S.	R. Betley, C. E. De Rance, W. Topley, W. Whitaker.
1884. Montreal ...	W. T. Blanford, F.R.S , Sec. G.S.	F. Adams, Prof. E. W. Claypole, W. Topley, W. Whitaker.
1885. Aberdeen ...	Prof. J. W. Judd, F.R.S., Sec. G.S.	C. E. De Rance, J. Horne, J. J. H. Teall, W. Topley.
1886. Birmingham	Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S.	W. J. Harrison, J. J. H. Teall, W. Topley, W. W. Watts.
1887. Manchester	Henry Woodward, LL.D., F.R.S., F.G.S.	J. E. Marr, J. J. H. Teall, W. Topley, W. W. Watts.
1888. Bath.........	Prof. W. Boyd Dawkins, M.A., F.R.S., F.G.S.	Prof G. A. Lebour, W. Topley, W W. Watts, H. B. Woodward.
1889. Newcastle-upon-Tyne	Prof. J. Geikie, LL.D., D.C.L., F.R.S., F.G.S.	Prof. G. A. Lebour, J. E. Marr, W. W. Watts, H. B. Woodward.
1890. Leeds	Prof. A. H. Green, M.A., F.R.S., F.G.S.	J. E. Bedford, Dr. F. H. Hatch, J. E. Marr, W. W. Watts.
1891. Cardiff......	Prof. T. Rupert Jones, F.R.S., F.G.S.	W. Galloway, J. E. Marr, Clement Reid, W. W. Watts.
1892. Edinburgh	Prof. C. Lapworth, LL.D., F.R.S., F.G.S.	H. M. Cadell, J. E. Marr, Clement Reid, W. W. Watts.
1893. Nottingham	J. J. H. Teall, M.A., F.R.S., F.G.S.	J. W. Carr, J. E. Marr, Clement Reid, W. W. Watts.
1894. Oxford......	L. Fletcher, M.A., F.R.S. ...	F. A. Bather, A. Harker, Clement Reid, W. W. Watts.
1895. Ipswich ...	W. Whitaker, B.A., F.R.S. ...	F. A. Bather, G. W. Lamplugh, H. A. Miers, Clement Reid.
1896. Liverpool...	J. E. Marr, M.A., F.R.S.......	J. Lomas, Prof. H. A. Miers, C. Reid.
1897. Toronto ...	Dr. G. M. Dawson, C.M.G., F.R.S.	Prof. A. P. Coleman, G. W. Lamplugh, Prof. H. A. Miers.
1898. Bristol......	W. H. Hudleston, F.R.S.......	G. W. Lamplugh, Prof. H. A. Miers, H. Pentecost.
1899. Dover	Sir Archibald Geikie, F.R.S.	J. W. Gregory, G. W. Lamplugh, Capt. McDakin, Prof. H. A. Miers.
1900. Bradford ...	Prof. W. J. Sollas, F.R.S. ...	H. L. Bowman, Rev. W. L. Carter, G. W. Lamplugh, H. W. Monckton.
1901. Glasgow ...	John Horne, F.R.S.	H. L. Bowman, H. W. Monckton.
1902. Belfast......	Lieut.-Gen. C. A. McMahon, F.R.S.	H. L. Bowman, H. W. Monckton, J. St. J. Phillips, H. J. Seymour.
1903. Southport	Prof. W. W. Watts, M.A., M.Sc.	H. L. Bowman, Rev. W. L. Carter, J. Lomas, H. W. Monckton.
1904. Cambridge	Aubrey Strahan, F.R.S.	H. L. Bowman, Rev. W. L. Carter, J. Lomas, H. Woods.
1905. South Africa	Prof. H. A. Miers, M.A., D.Sc., F.R.S.	H. L. Bowman, J. Lomas, Dr. Molengraaff, Prof. A. Young, Prof. R. B. Young.

Date and Place	Presidents	Secretaries
1906. York.........	G. W. Lamplugh, F.R.S.	H. L. Bowman, Rev. W. L. Carter, Rev. W. Johnson, J. Lomas.
1907. Leicester...	Prof. J. W. Gregory, F.R.S....	Dr. F. W. Bennett, Rev. W. L. Carter, Prof. T. Groom, J. Lomas.
1908. Dublin......	Prof. John Joly, F.R.S.	Rev. W. L. Carter, J. Lomas, Prof. S. H. Reynolds, H. J. Seymour.
1909. Winnipeg...	Dr. A. Smith Woodward, F.R.S.	W. L. Carter, Dr. A. R. Dwerryhouse, R. T. Hodgson, Prof. S. H. Reynolds.
1910. Sheffield ...	Prof. A. P. Coleman, F.R.S...	W. L. Carter, Dr. A. R. Dwerryhouse, B. Hobson, Prof. S. H. Reynolds.

BIOLOGICAL SCIENCES.

COMMITTEE OF SCIENCES, IV.—ZOOLOGY, BOTANY, PHYSIOLOGY, ANATOMY.

1832. Oxford......	Rev. P. B. Duncan, F.G.S. ...	Rev. Prof. J. S. Henslow.
1833. Cambridge[1]	Rev. W. L. P. Garnons, F.L.S.	C. C. Babington, D. Don.
1834. Edinburgh	Prof. Graham.....................	W. Yarrell, Prof. Burnett.

SECTION D.—ZOOLOGY AND BOTANY.

1835. Dublin......	Dr. Allman........................	J. Curtis, Dr. Litton.
1836. Bristol......	Rev. Prof. Henslow	J. Curtis, Prof. Don, Dr. Riley, S. Rootsey.
1837. Liverpool...	W. S. MacLeay.................	C. C. Babington, Rev. L. Jenyns, W. Swainson.
1838. Newcastle	Sir W. Jardine, Bart.	J. E. Gray, Prof. Jones, R. Owen, Dr. Richardson.
1839. Birmingham	Prof. Owen, F.R.S.	E. Forbes, W. Ick, R. Patterson.
1840. Glasgow ...	Sir W. J. Hooker, LL.D.......	Prof. W. Couper, E. Forbes, R. Patterson.
1841. Plymouth...	John Richardson, M.D., F.R.S.	J. Couch, Dr. Lankester, R. Patterson.
1842. Manchester	Hon. and Very Rev. W. Herbert, LL.D., F.L.S.	Dr. Lankester, R. Patterson, J. A. Turner.
1843. Cork.........	William Thompson, F.L.S. ...	G. J. Allman, Dr. Lankester, R. Patterson.
1844. York.........	Very Rev. the Dean of Manchester.	Prof. Allman, H. Goodsir, Dr. King, Dr. Lankester.
1845. Cambridge	Rev. Prof. Henslow, F.L.S....	Dr. Lankester, T. V. Wollaston.
1846. Southampton.	Sir J. Richardson, M.D., F.R.S.	Dr. Lankester, T. V. Wollaston, H. Wooldridge.
1847. Oxford......	H. E. Strickland, M.A., F.R.S.	Dr. Lankester, Dr. Melville, T. V. Wollaston.

SECTION D (*continued*).—ZOOLOGY AND BOTANY, INCLUDING PHYSIOLOGY.

[For the Presidents and Secretaries of the Anatomical and Physiological Subsections and the temporary Section E of Anatomy and Medicine, see p. lxxviii.]

1848. Swansea ...	L. W. Dillwyn, F.R.S.	Dr. R. Wilbraham Falconer, A. Henfrey, Dr. Lankester.
1849. Birmingham	William Spence, F.R.S.	Dr. Lankester, Dr. Russell.
1850. Edinburgh	Prof. Goodsir, F.R.S., F.R.S.E.	Prof. J. H. Bennett, M.D., Dr. Lankester, Dr. Douglas Maclagan.
1851. Ipswich ...	Rev. Prof. Henslow, M.A., F.R.S.	Prof. Allman, F. W. Johnston, Dr. E. Lankester.
1852. Belfast......	W. Ogilby	Dr. Dickie, George C. Hyndman, Dr. Edwin Lankester.
1853. Hull.........	C. C. Babington, M.A., F.R.S.	Robert Harrison, Dr. E. Lankester.

[1] At this Meeting Physiology and Anatomy were made a separate Committee, for Presidents and Secretaries of which see p. lxxviii.

Date and Place	Presidents	Secretaries
1854. Liverpool...	Prof. Balfour, M.D., F.R.S....	Isaac Byerley, Dr. E. Lankester.
1855. Glasgow ...	Rev. Dr. Fleeming, F.R.S.E.	William Keddie, Dr. E. Lankester.
1856. Cheltenham	Thomas Bell, F.R.S., Pres.L.S.	Dr. J. Abercrombie, Prof. Buckman, Dr. E. Lankester.
1857. Dublin......	Prof. W. H. Harvey, M.D., F.R.S.	Prof. J. R. Kinahan, Dr. E. Lankester, Robert Patterson, Dr. W. E. Steele.
1858. Leeds	C. C. Babington, M.A., F.R.S.	Henry Denny, Dr. Heaton, Dr. E. Lankester, Dr. E. Perceval Wright.
1859. Aberdeen...	Sir W. Jardine, Bart., F.R.S.E.	Prof. Dickie, M.D., Dr. E. Lankester, Dr. Ogilvy.
1860. Oxford......	Rev. Prof. Henslow, F.L.S....	W. S. Church, Dr. E. Lankester, P. L. Sclater, Dr. E. Perceval Wright.
1861. Manchester	Prof. C. C. Babington, F.R.S.	Dr. T. Alcock, Dr. E. Lankester, Dr P. L. Sclater, Dr. E. P. Wright.
1862. Cambridge	Prof. Huxley, F.R.S.	Alfred Newton, Dr. E. P. Wright.
1863. Newcastle	Prof. Balfour, M.D., F.R.S....	Dr. E. Charlton, A. Newton, Rev. H. B. Tristram, Dr. E. P. Wright.
1864. Bath.........	Dr. John E. Gray, F.R.S. ...	H. B. Brady, C. E. Broom, H. T. Stainton, Dr. E. P. Wright.
1865. Birmingham.[1]	T. Thomson, M.D., F.R.S. ...	Dr. J. Anthony, Rev. C. Clarke, Rev. H. B. Tristram, Dr. E. P. Wright.

SECTION D (*continued*).—BIOLOGY.

1866. Nottingham	Prof. Huxley, F.R.S.—*Dep. of Physiol.*, Prof. Humphry, F.R.S.—*Dep. of Anthropol.*, A. R. Wallace.	Dr. J. Beddard, W. Felkin, Rev. H. B. Tristram, W. Turner, E. B. Tylor, Dr. E. P. Wright.
1867. Dundee ...	Prof. Sharpey, M.D., Sec. R.S. —*Dep. of Zool. and Bot.*, George Busk, M.D., F.R.S.	C. Spence Bate, Dr. S. Cobbold, Dr. M. Foster, H. T. Stainton, Rev. H. B. Tristram, Prof. W. Turner.
1868. Norwich ...	Rev. M. J. Berkeley, F.L.S. —*Dep. of Physiology*, W. H. Flower, F.R.S.	Dr. T. S. Cobbold, G. W. Firth, Dr. M. Foster, Prof. Lawson, H. T. Stainton, Rev. Dr. H. B. Tristram, Dr. E. P. Wright.
1869. Exeter......	George Busk, F.R.S., F.L.S. —*Dep. of Bot. and Zool.*, C. Spence Bate, F.R.S.—*Dep. of Ethno.*, E. B. Tylor.	Dr. T. S. Cobbold, Prof. M. Foster, E. Ray Lankester, Prof. Lawson, H. T. Stainton, Rev. H. B. Tristram.
1870. Liverpool...	Prof. G. Rolleston, M.A., M.D., F.R.S., F.L.S.—*Dep. of Anat. and Physiol.*, Prof. M. Foster, M.D., F.L.S.—*Dep. of Ethno.*, J. Evans, F.R.S.	Dr. T. S. Cobbold, Sebastian Evans, Prof. Lawson, Thos. J. Moore, H. T. Stainton, Rev. H. B. Tristram, C. Staniland Wake, E. Ray Lankester.
1871. Edinburgh.	Prof. Allen Thomson, M.D., F.R.S.—*Dep. of Bot. and Zool.*, Prof. Wyville Thomson, F.R.S.—*Dep. of Anthropol.*, Prof. W. Turner, M.D.	Dr. T. R. Fraser, Dr. Arthur Gamgee, E. Ray Lankester, Prof. Lawson, H. T. Stainton, C. Staniland Wake, Dr. W. Rutherford, Dr. Kelburne King.
1872. Brighton ...	Sir J. Lubbock, Bart., F.R.S.—*Dep. of Anat. and Physiol.*, Dr. Burdon Sanderson, F.R.S.—*Dep. of Anthropol.*, Col. A. Lane Fox, F.G.S.	Prof. Thiselton-Dyer, H. T. Stainton, Prof. Lawson, F. W. Rudler, J. H. Lamprey, Dr. Gamgee, E. Ray Lankester, Dr. Pye-Smith.
1873. Bradford ...	Prof. Allman, F.R.S.—*Dep. of Anat. and Physiol.*, Prof. Rutherford, M.D.—*Dep. of Anthropol.*, Dr. Beddoe, F.R.S.	Prof. Thiselton-Dyer, Prof. Lawson, R. M'Lachlan, Dr. Pye-Smith, E. Ray Lankester, F. W. Rudler, J. H. Lamprey.

[1] The title of Section D was changed to Biology.

Date and Place	Presidents	Secretaries
1874. Belfast.....	Prof. Redfern, M.D.—*Dep. of Zool. and Bot.*, Dr. Hooker, C.B., Pres.R.S.—*Dep. of Anthrop.*, Sir W. R. Wilde, M.D.	W. T. Thiselton-Dyer, R. O. Cunningham, Dr. J. J. Charles, Dr. P. H. Pye-Smith, J. J. Murphy, F. W. Rudler.
1875. Bristol	P. L. Sclater, F.R.S.—*Dep. of Anat. and Physiol.*, Prof. Cleland, F.R.S.—*Dep. of Anth.*, Prof. Rolleston, F.R.S.	E. R. Alston, Dr. McKendrick, Prof. W. R. M'Nab, Dr. Martyn, F. W. Rudler, Dr. P. H. Pye-Smith, Dr. W. Spencer.
1876. Glasgow ...	A. Russel Wallace, F.L.S.—*Dep. of Zool. and Bot.*, Prof. A. Newton, F.R.S.—*Dep. of Anat. and Physiol.*, Dr. J. G. McKendrick.	E. R. Alston, Hyde Clarke, Dr. Knox, Prof. W. R. M'Nab, Dr. Muirhead, Prof. Morrison Watson.
1877. Plymouth...	J. Gwyn Jeffreys, F.R.S.—*Dep. of Anat. and Physiol.*, Prof. Macalister.—*Dep. of Anthropol.*, F. Galton, F.R.S.	E. R. Alston, F. Brent, Dr. D. J. Cunningham, Dr. C. A. Hingston, Prof. W. R. M'Nab, J. B. Rowe, F. W. Rudler.
1878. Dublin	Prof. W. H. Flower, F.R.S.—*Dep. of Anthropol.*, Prof. Huxley, Sec. R.S.—*Dep. of Anat. and Physiol.*, R. McDonnell, M.D., F.R.S.	Dr. R. J. Harvey, Dr. T. Hayden, Prof. W. R. M'Nab, Prof. J. M. Purser, J. B. Rowe, F. W. Rudler.
1879. Sheffield ...	Prof. St. George Mivart, F.R.S.—*Dep. of Anthropol.*, E. B. Tylor, D.C.L., F.R.S. —*Dep. of Anat. and Physiol.*, Dr. Pye-Smith.	Arthur Jackson, Prof. W. R. M'Nab, J. B. Rowe, F. W. Rudler, Prof. Schäfer.
1880. Swansea ...	A. C. L. Günther, F.R.S.—*Dep. of Anat. & Physiol.*, F. M. Balfour, F.R.S.—*Dep. of Anthropol.*, F. W. Rudler.	G. W. Bloxam, John Priestley, Howard Saunders, Adam Sedgwick.
1881. York.........	R. Owen, F.R.S.—*Dep. of Anthropol.*, Prof. W.H. Flower, F.R.S.—*Dep. of Anat. and Physiol.*, Prof. J. S. Burdon Sanderson, F.R.S.	G. W. Bloxam, W. A. Forbes, Rev. W. C. Hey, Prof. W. R. M'Nab, W. North, John Priestley, Howard Saunders, H. E. Spencer.
1882. Southampton.	Prof. A. Gamgee, M.D., F.R.S. —*Dep. of Zool. and Bot.*, Prof. M. A. Lawson, F.L.S. —*Dep. of Anthropol.*, Prof. W. Boyd Dawkins, F.R.S.	G. W. Bloxam, W. Heape, J. B. Nias, Howard Saunders, A. Sedgwick, T. W. Shore, jun.
1883. Southport	Prof. E. Ray Lankester, M.A., F.R.S.—*Dep. of Anthropol.*, W. Pengelly, F.R.S.	G. W. Bloxam, Dr. G. J. Haslam, W. Heape, W. Hurst, Prof. A. M. Marshall, Howard Saunders, Dr. G. A. Woods.
1884. Montreal [1]...	Prof. H. N. Moseley, M.A., F.R.S.	Prof. W. Osler, Howard Saunders, A. Sedgwick, Prof. R. R. Wright.
1885. Aberdeen...	Prof. W. C. M'Intosh, M.D., LL.D., F.R.S., F.R.S.E.	W. Heape, J. McGregor-Robertson, J. Duncan Matthews, Howard Saunders, H. Marshall Ward.
1886. Birmingham	W. Carruthers, Pres. L.S., F.R.S., F.G.S.	Prof. T. W. Bridge, W. Heape, Prof. W. Hillhouse, W. L. Sclater, Prof. H. Marshall Ward.
1887. Manchester	Prof. A. Newton, M.A., F.R.S., F.L.S., V.P.Z.S.	C. Bailey, F. E. Beddard, S. F. Harmer, W. Heape, W. L. Sclater, Prof. H. Marshall Ward.

[1] Anthropology was made a separate Section, see p. lxxxv.

Date and Place	Presidents	Secretaries
1888. Bath.........	W. T. Thiselton-Dyer, C.M.G., F.R.S., F.L.S.	F. E. Beddard, S. F. Harmer, Prof. H. Marshall Ward, W. Gardiner. Prof. W. D. Halliburton.
1889. Newcastle-upon-Tyne	Prof. J. S. Burdon Sanderson, M.A., M.D., F.R.S.	C. Bailey, F. E. Beddard, S. F. Harmer, Prof. T. Oliver, Prof. H. Marshall Ward.
1890. Leeds	Prof. A. Milnes Marshall, M.A., M.D., D.Sc., F.R.S.	S. F. Harmer, Prof. W. A. Herdman, S. J. Hickson, F. W. Oliver H. Wager, H. Marshall Ward.
1891. Cardiff......	Francis Darwin, M.A., M.B., F.R.S., F.L.S.	F. E. Beddard, Prof. W. A. Herdman, Dr. S. J. Hickson, G. Murray, Prof. W. N. Parker, H. Wager.
1892. Edinburgh	Prof. W. Rutherford, M.D., F.R.S., F.R.S.E.	G. Brook, Prof. W. A. Herdman, G. Murray, W. Stirling, H. Wager.
1893. Nottingham[1]	Rev. Canon H. B. Tristram, M.A., LL.D., F.R.S.	G. C. Bourne, J. B. Farmer, Prof. W. A. Herdman, S. J. Hickson, W. B. Ransom, W. L. Sclater.
1894. Oxford[2] ...	Prof. I. Bayley Balfour, M.A., F.R.S.	W. W. Benham, Prof. J. B. Farmer, Prof. W. A. Herdman, Prof. S. J. Hickson, G. Murray, W. L. Sclater.

SECTION D (*continued*).—ZOOLOGY.

1895. Ipswich ...	Prof. W. A. Herdman, F.R.S.	G. C. Bourne, H. Brown, W. E. Hoyle, W. L. Sclater.
1896. Liverpool...	Prof. E. B. Poulton, F.R.S. ...	H. O. Forbes, W. Garstang, W. E. Hoyle.
1897. Toronto ...	Prof. L. C. Miall, F.R.S.	W. Garstang, W. E. Hoyle, Prof. E. E. Prince.
1898. Bristol.	Prof. W. F. R. Weldon, F.R.S.	Prof. R. Boyce, W. Garstang, Dr. A. J. Harrison, W. E. Hoyle.
1899. Dover	Adam Sedgwick, F.R.S.	W. Garstang, J. Graham Kerr.
1900 Bradford ...	Dr. R. H. Traquair, F.R.S. ...	W. Garstang, J. G. Kerr, T. H. Taylor, Swale Vincent.
1901. Glasgow ...	Prof. J. Cossar Ewart, F.R.S.	J. G. Kerr, J. Rankin, J. Y. Simpson.
1902. Belfast......	Prof. G. B. Howes, F.R.S. ...	Prof. J. G. Kerr, R. Patterson, J. Y. Simpson.
1903. Southport	Prof. S. J. Hickson, F.R.S. ...	Dr. J. H. Ashworth, J. Barcroft, A. Quayle, Dr. J. Y. Simpson, Dr. H. W. M. Tims.
1904. Cambridge	William Bateson, F.R.S.	Dr. J. H. Ashworth, L. Doncaster, Prof. J. Y. Simpson, Dr. H. W. M. Tims.
1905. SouthAfrica	G. A. Boulenger, F.R.S.	Dr. Pakes, Dr. Purcell, Dr. H. W. M. Tims, Prof. J. Y. Simpson.
1906. York.........	J. J. Lister, F.R.S.	Dr. J. H. Ashworth, L. Doncaster, Oxley Grabham, Dr. H. W. M. Tims.
1907. Leicester ...	Dr. W. E. Hoyle, M.A.........	Dr. J. H. Ashworth, L. Doncaster, E. E. Lowe, Dr. H. W. M. Tims.
1908. Dublin......	Dr. S. F. Harmer, F.R.S.......	Dr. J. H. Ashworth, L. Doncaster, Prof. A. Fraser, Dr. H. W. M. Tims
1909. Winnipeg...	Dr. A. E. Shipley, F.R.S. ...	C. A. Baragar, C. L. Boulenger, Dr. J. Pearson, Dr. H. W. M. Tims.
1910. Sheffield ...	Prof. G. C. Bourne, F.R.S. ...	Dr. J. H. Ashworth, L. Doncaster, T. J. Evans, Dr. H. W. M. Tims.

[1] Physiology was made a separate Section, see p. lxxxvi.
[2] The title of Section D was changed to Zoology.

Date and Place	Presidents	Secretaries

ANATOMICAL AND PHYSIOLOGICAL SCIENCES.

COMMITTEE OF SCIENCES, V.—ANATOMY AND PHYSIOLOGY.

1833. Cambridge	Dr. J. Haviland	Dr. H. J. H. Bond, Mr. G. E. Paget.
1834. Edinburgh	Dr. Abercrombie	Dr. Roget, Dr. William Thomson.

SECTION E (UNTIL 1847).—ANATOMY AND MEDICINE.

1835. Dublin	Dr. J. C. Pritchard	Dr. Harrison, Dr. Hart.
1836. Bristol	Dr. P. M. Roget, F.R.S.	Dr. Symonds.
1837. Liverpool	Prof. W. Clark, M.D.	Dr. J. Carson, jun., James Long, Dr. J. R. W. Vose.
1838. Newcastle	T. E. Headlam, M.D.	T. M. Greenhow, Dr. J. R. W. Vose.
1839. Birmingham	John Yelloly, M.D., F.R.S.	Dr. G. O. Rees, F. Ryland.
1840. Glasgow	James Watson, M.D.	Dr. J. Brown, Prof. Couper, Prof. Reid.

SECTION E.—PHYSIOLOGY.

1841. Plymouth	P. M. Roget, M.D., Sec. R.S.	J. Butter, J. Fuge, Dr. R. S. Sargent.
1842. Manchester	Edward Holme, M.D., F.L.S.	Dr. Chaytor, Dr. R. S. Sargent.
1843. Cork	Sir James Pitcairn, M.D.	Dr. John Popham, Dr. R. S. Sargent.
1844. York	J. C. Pritchard, M.D.	I. Erichsen, Dr. R. S. Sargent.
1845. Cambridge	Prof. J. Haviland, M.D.	Dr. R. S. Sargent, Dr. Webster.
1846. Southampton.	Prof. Owen, M.D., F.R.S.	C. P. Keele, Dr. Laycock, Dr. Sargent.
1847. Oxford[1]	Prof. Ogle, M.D., F.R.S.	T. K. Chambers, W. P. Ormerod.

PHYSIOLOGICAL SUBSECTIONS OF SECTION D.

1850. Edinburgh	Prof. Bennett, M.D., F.R.S.E.	
1855. Glasgow	Prof. Allen Thomson, F.R.S.	Prof. J. H. Corbett, Dr. J. Struthers.
1857. Dublin	Prof. R. Harrison, M.D.	Dr. R. D. Lyons, Prof. Redfern.
1858. Leeds	Sir B. Brodie, Bart., F.R.S.	C. G. Wheelhouse.
1859. Aberdeen	Prof. Sharpey, M.D., Sec.R.S.	Prof. Bennett, Prof. Redfern.
1860. Oxford	Prof. G. Rolleston, M.D., F.L.S.	Dr. R. M'Donnell, Dr. Edward Smith.
1861. Manchester	Dr. John Davy, F.R.S.	Dr. W. Roberts, Dr. Edward Smith.
1862. Cambridge	G. E. Paget, M.D.	G. F. Helm, Dr. Edward Smith.
1863. Newcastle	Prof. Rolleston, M.D., F.R.S.	Dr. D. Embleton, Dr. W. Turner.
1864. Bath	Dr. Edward Smith, F.R.S.	J. S. Bartrum, Dr. W. Turner.
1865. Birmingham.[2]	Prof. Acland, M.D., LL.D., F.R.S.	Dr. A. Fleming, Dr. P. Heslop, Oliver Pembleton, Dr. W. Turner.

GEOGRAPHICAL AND ETHNOLOGICAL SCIENCES.

[For Presidents and Secretaries for Geography previous to 1851, see Section C, p. lxxi.]

ETHNOLOGICAL SUBSECTIONS OF SECTION D.

1846. Southampton	Dr. J. C. Pritchard	Dr. King.
1847. Oxford	Prof. H. H. Wilson, M.A.	Prof. Buckley.
1848. Swansea	....	G. Grant Francis.
1849. Birmingham	....	Dr. R. G. Latham.
1850. Edinburgh	Vice-Admiral Sir A. Malcolm	Daniel Wilson.

[1] Sections D and E were incorporated under the title of 'Section D—Zoology and Botany, including Physiology' (see p. lxxiv). Section E, being then vacant, was assigned in 1851 to Geography.

[2] *Vide* note on page lxxiv.

SECTION E.—GEOGRAPHY AND ETHNOLOGY.

Date and Place	Presidents	Secretaries
1851. Ipswich ...	Sir R. I. Murchison, F.R.S., Pres. R.G.S.	R. Cull, Rev. J. W. Donaldson, Dr. Norton Shaw.
1852. Belfast......	Col. Chesney, R.A., D.C.L., F.R.S.	R. Cull, E. MacAdam, Dr. Norton Shaw.
1853. Hull.........	R. G. Latham, M.D., F.R.S.	R. Cull, Rev. H. W. Kemp, Dr. Norton Shaw.
1854. Liverpool...	Sir R. I. Murchison, D.C.L., F.R.S.	Richard Cull, Rev. H. Higgins, Dr. Ihne, Dr. Norton Shaw.
1855. Glasgow ...	Sir J. Richardson, M.D., F.R.S.	Dr. W. G. Blackie, R. Cull, Dr. Norton Shaw.
1856. Cheltenham	Col. Sir H. C. Rawlinson, K.C.B.	R. Cull, F. D. Hartland, W. H. Rumsey, Dr. Norton Shaw.
1857. Dublin......	Rev. Dr. J. Henthorn Todd, Pres.R.I.A.	R. Cull, S. Ferguson, Dr. R. R. Madden, Dr. Norton Shaw.
1858. Leeds	Sir R. I. Murchison, G.C.St.S., F.R.S.	R. Cull, F. Galton, P. O'Callaghan, Dr. Norton Shaw, T. Wright.
1859. Aberdeen...	Rear-Admiral Sir James Clerk Ross, D.C.L., F.R.S.	Richard Cull, Prof. Geddes, Dr. Norton Shaw.
1860. Oxford......	Sir R. I. Murchison, D.C.L., F.R.S.	Capt. Burrows, Dr. J. Hunt, Dr. C. Lemprière, Dr. Norton Shaw.
1861. Manchester	John Crawfurd, F.R.S.........	Dr. J. Hunt, J. Kingsley, Dr. Norton Shaw, W. Spottiswoode.
1862. Cambridge	Francis Galton, F.R.S..........	J. W. Clarke, Rev. J. Glover, Dr. Hunt, Dr. Norton Shaw, T. Wright.
1863. Newcastle	Sir R. I. Murchison, K.C.B., F.R.S.	C. Carter Blake, Hume Greenfield, C. R. Markham, R. S. Watson.
1864. Bath.........	Sir R. I. Murchison, K.C.B., F.R.S.	H. W. Bates, C. R. Markham, Capt. R. M. Murchison, T. Wright.
1865. Birmingham.	Major-General Sir H. Rawlinson, M.P., K.C.B., F.R.S.	H. W. Bates, S. Evans, G. Jabet, C. R. Markham, Thomas Wright.
1866. Nottingham	Sir Charles Nicholson, Bart., LL.D.	H. W. Bates, Rev. E. T. Cusins, R. H. Major, Clements R. Markham, D. W. Nash, T. Wright.
1867. Dundee ...	Sir Samuel Baker, F.R.G.S.	H. W. Bates, Cyril Graham, C. R. Markham, S. J. Mackie, R. Sturrock.
1868. Norwich ...	Capt. G. H. Richards, R.N., F.R.S.	T. Baines, H. W. Bates, Clements R. Markham, T. Wright.

SECTION E (*continued*).—GEOGRAPHY.

Date and Place	Presidents	Secretaries
1869. Exeter......	Sir Bartle Frere, K.C.B., LL.D., F.R.G.S.	H. W. Bates, Clements R. Markham, J. H. Thomas.
1870. Liverpool...	Sir R. I. Murchison, Bt., K.C.B., LL.D., D.C.L., F.R.S., F.G.S.	H. W. Bates, David Buxton, Albert J. Mott, Clements R. Markham.
1871. Edinburgh	Colonel Yule, C.B., F.R.G.S.	A. Buchan, A. Keith Johnston, Clements R. Markham, J. H. Thomas.
1872. Brighton ...	Francis Galton, F.R.S.........	H. W. Bates, A. Keith Johnston, Rev. J. Newton, J. H. Thomas.
1873. Bradford ...	Sir Rutherford Alcock, K.C.B.	H. W. Bates, A. Keith Johnston, Clements R. Markham.
1874. Belfast......	Major Wilson, R.E., F.R.S., F.R.G.S.	E. G. Ravenstein, E. C. Rye, J. H. Thomas.
1875. Bristol......	Lieut.-General Strachey, C.S.I., R.E., F.R.S., F.R.G.S.	H. W. Bates, E. C. Rye, F. F. Tuckett.
1876. Glasgow ...	Capt. Evans, C.B., F.R.S......	H. W. Bates, E. C. Rye, R. O. Wood.
1877. Plymouth...	Adm. Sir E. Ommanney, C.B.	H. W. Bates, F. E. Fox, E. C. Rye.

Date and Place	Presidents	Secretaries
1878. Dublin......	Prof. Sir C. Wyville Thomson, LL.D., F.R.S., F.R.S.E.	John Coles, E. C. Rye.
1879. Sheffield ...	Clements R. Markham, C.B., F.R.S., Sec. R.G.S.	H. W. Bates, C. E. D. Black, E. C. Rye.
1880. Swansea ...	Lieut.-Gen. Sir J. H. Lefroy, C.B., K.C.M.G., R.A., F.R.S.	H. W. Bates, E. C. Rye.
1881. York.........	Sir J. D. Hooker, K.C.S.I., C.B., F.R.S.	J. W. Barry, H. W. Bates.
1882. Southampton.	Sir R. Temple, Bart., G.C.S.I., F.R.G.S.	E. G. Ravenstein, E. C. Rye.
1883. Southport...	Lieut.-Col. H. H. Godwin-Austen, F.R.S.	John Coles, E. G. Ravenstein, E. C. Rye.
1884. Montreal ...	Gen. Sir J. H. Lefroy, C.B., K.C.M.G., F.R.S., V.P.R.G.S.	Rev. Abbé Laflamme, J. S. O'Halloran, E. G. Ravenstein, J. F. Torrance.
1885. Aberdeen...	Gen. J. T. Walker, C.B., R.E., LL.D., F.R.S.	J. S. Keltie, J. S. O'Halloran, E. G. Ravenstein, Rev. G. A. Smith.
1886. Birmingham.	Maj.-Gen. Sir. F. J. Goldsmid, K.C.S.I., C.B., F.R.G.S.	F. T. S. Houghton, J. S. Keltie, E. G. Ravenstein.
1887. Manchester	Col. Sir C. Warren, R.E., G.C.M.G., F.R.S., F.R.G.S.	Rev. L. C. Casartelli, J. S. Keltie, H. J. Mackinder, E. G. Ravenstein.
1888. Bath.........	Col. Sir C. W. Wilson, R.E., K.C.B., F.R.S., F.R.G.S.	J. S. Keltie, H. J. Mackinder, E. G. Ravenstein.
1889. Newcastle-upon-Tyne	Col. Sir F. de Winton, K.C.M.G., C.B., F.R.G.S.	J. S. Keltie, H. J. Mackinder, R. Sulivan, A. Silva White.
1890. Leeds	Lieut.-Col. Sir R. Lambert Playfair, K.C.M.G., F.R.G.S.	A. Barker, John Coles, J. S. Keltie, A. Silva White.
1891. Cardiff......	E. G. Ravenstein, F.R.G.S., F.S.S.	John Coles, J. S. Keltie, H. J. Mackinder, A. Silva White, Dr. Yeats.
1892. Edinburgh	Prof. J. Geikie, D.C.L., F.R.S., V.P.R.Scot.G.S.	J. G. Bartholomew, John Coles, J. S. Keltie, A. Silva White.
1893. Nottingham	H. Seebohm, Sec. R.G.S., F.L.S., F.Z.S.	Col. F. Bailey, John Coles, H. O. Forbes, Dr. H. R. Mill.
1894. Oxford......	Capt. W. J. L. Wharton, R.N., F.R.S.	John Coles, W. S. Dalgleish, H. N. Dickson, Dr. H. R. Mill.
1895. Ipswich ...	H. J. Mackinder, M.A., F.R.G.S.	John Coles, H. N. Dickson, Dr. H. R. Mill, W. A. Taylor.
1896. Liverpool...	Major L. Darwin, Sec. R.G.S.	Col. F. Bailey, H. N. Dickson, Dr. H. R. Mill, E. C. DuB. Phillips.
1897. Toronto ...	J. Scott Keltie, LL.D.	Col. F. Bailey, Capt. Deville, Dr. H. R. Mill, J. B. Tyrrell.
1898. Bristol......	Col. G. Earl Church, F.R.G.S.	H. N. Dickson, Dr. H. R. Mill, H. C. Trapnell.
1899. Dover	Sir John Murray, F.R.S.	H. N. Dickson, Dr. H. O. Forbes, Dr. H. R. Mill.
1900. Bradford ...	Sir George S. Robertson, K.C.S.I.	H. N. Dickson, E. Heawood, E. R. Wethey.
1901. Glasgow ...	Dr. H. R. Mill, F.R.G.S.	H. N. Dickson, E. Heawood, G. Sandeman, A. C. Turner.
1902. Belfast......	Sir T. H. Holdich, K.C.B. ...	G. G. Chisholm, E. Heawood, Dr. A. J. Herbertson, Dr. J. A. Lindsay.
1903. Southport...	Capt. E. W. Creak, R.N., C.B., F.R.S.	E. Heawood, Dr. A. J. Herbertson, E. A. Reeves, Capt. J. C. Underwood.
1904. Cambridge	Douglas W. Freshfield.........	E. Heawood, Dr. A. J. Herbertson, H. Y. Oldham, E. A. Reeves.
1905. SouthAfrica	Adm. Sir W. J. L. Wharton, R.N., K.C.B., F.R.S.	A. H. Cornish-Bowden, F. Flowers, Dr. A. J. Herbertson, H. Y. Oldham.
1906. York.	Rt. Hon. Sir George Goldie, K.C.M.G., F.R.S.	E. Heawood, Dr. A. J. Herbertson, E. A. Reeves, G. Yeld.

Date and Place	Presidents	Secretaries
1907. Leicester ...	George G. Chisholm, M.A. ...	E. Heawood, O. J. R. Howarth, E. A. Reeves, T. Walker.
1908. Dublin	Major E. H. Hills, C.M.G., R.E.	W. F. Bailey, W. J. Barton, O. J. R. Howarth, E. A. Reeves.
1909. Winnipeg...	Col. Sir D. Johnston, K.C.M.G., C.B., R.E.	G. G. Chisholm, J. McFarlane, A. McIntyre.
1910. Sheffield ...	Prof. A. J. Herbertson, M A., Ph.D.	Rev. W. J. Barton, Dr. R. Brown, J. McFarlane, E. A. Reeves.

STATISTICAL SCIENCE.

COMMITTEE OF SCIENCES, VI.—STATISTICS.

1833. Cambridge	Prof. Babbage, F.R.S.	J. E. Drinkwater.
1834. Edinburgh	Sir Charles Lemon, Bart.......	Dr. Cleland, C. Hope Maclean.

SECTION F.—STATISTICS.

1835. Dublin	Charles Babbage, F.R.S.	W. Greg, Prof. Longfield.
1836. Bristol......	Sir Chas. Lemon, Bart., F.R.S.	Rev. J. E. Bromby, C. B. Fripp, James Heywood.
1837. Liverpool...	Rt. Hon. Lord Sandon	W. R. Greg, W. Langton, Dr. W. C. Tayler.
1838. Newcastle	Colonel Sykes, F.R.S.	W. Cargill, J. Heywood, W. R. Wood
1839. Birmingham.	Henry Hallam, F.R.S.........	F. Clarke, R. W. Rawson, Dr. W. C. Tayler.
1840. Glasgow ...	Lord Sandon, M.P., F.R.S.	C. R. Baird, Prof. Ramsay, R. W. Rawson.
1841. Plymouth...	Lieut.-Col. Sykes, F.R.S.......	Rev. Dr. Byrth, Rev. R. Luney, R. W. Rawson.
1842. Manchester	G. W. Wood, M.P., F.L.S. ...	Rev. R. Luney, G. W. Ormerod, Dr. W. Cooke Tayler.
1843. Cork.........	Sir C. Lemon, Bart., M.P. ...	Dr. D. Bullen, Dr. W. Cooke Tayler.
1844. York.........	Lieut.-Col. Sykes, F.R.S., F.L.S.	J. Fletcher, J. Heywood, Dr. Laycock.
1845. Cambridge	Rt. Hon. the Earl Fitzwilliam	J. Fletcher, Dr. W. Cooke Tayler.
1846. Southampton.	G. R. Porter, F.R.S.	J. Fletcher, F. G. P. Neison, Dr. W. C. Tayler, Rev. T. L. Shapcott.
1847. Oxford......	Travers Twiss, D.C.L., F.R.S.	Rev. W. H. Cox, J. J. Danson, F. G. P. Neison.
1848. Swansea ...	J. H. Vivian, M.P., F.R.S. ...	J. Fletcher, Capt. R. Shortrede.
1849. Birmingham.	Rt. Hon. Lord Lyttelton......	Dr. Finch, Prof. Hancock, F. P. G. Neison.
1850. Edinburgh	Very Rev. Dr. John Lee, V.P.R.S.E.	Prof. Hancock, J. Fletcher, Dr. J. Stark.
1851. Ipswich ...	Sir John P. Boileau, Bart. ...	J. Fletcher, Prof. Hancock.
1852. Belfast......	His Grace the Archbishop of Dublin.	Prof. Hancock, Prof. Ingram, James MacAdam, jun.
1853. Hull.........	James Heywood, M.P., F.R.S.	Edward Cheshire, W. Newmarch.
1854. Liverpool...	Thomas Tooke, F.R.S.	E. Cheshire, J. T. Danson, Dr. W. H. Duncan, W. Newmarch.
1855. Glasgow ...	R. Monckton Milnes, M.P. ...	J. A. Campbell, E. Cheshire, W. Newmarch, Prof. R. H. Walsh.

SECTION F (*continued*).—ECONOMIC SCIENCE AND STATISTICS.

1856. Cheltenham	Rt. Hon. Lord Stanley, M.P.	Rev. C. H. Bromby, E. Cheshire, Dr. W. N. Hancock, W. Newmarch, W. M. Tartt.
1857. Dublin......	His Grace the Archbishop of Dublin, M.R.I.A.	Prof. Cairns, Dr. H. D. Hutton, W. Newmarch.
1858. Leeds	Edward Baines	T. B. Baines, Prof. Cairns, S. Brown, Capt. Fishbourne, Dr. J. Strang.

Date and Place	Presidents	Secretaries
1859. Aberdeen ...	Col. Sykes, M.P., F.R.S.	Prof. Cairns, Edmund Macrory, A. M. Smith, Dr. John Strang.
1860. Oxford	Nassau W. Senior, M.A.	Edmund Macrory, W. Newmarch, Prof. J. E. T. Rogers.
1861. Manchester	William Newmarch, F.R.S....	David Chadwick, Prof. R. C. Christie, E. Macrory, Prof. J. E. T. Rogers.
1862. Cambridge	Edwin Chadwick, C.B.	H. D. Macleod, Edmund Macrory.
1863. Newcastle	William Tite, M.P., F.R.S. ...	T. Doubleday, Edmund Macrory, Frederick Purdy, James Potts.
1864. Bath	W. Farr, M.D., D.C.L., F.R.S.	E. Macrory, E. T. Payne, F. Purdy.
1865. Birmingham.	Rt. Hon. Lord Stanley, LL.D., M.P.	G. J. D. Goodman, G. J. Johnston, E. Macrory.
1866. Nottingham	Prof. J. E. T. Rogers	R. Birkin, jun., Prof. Leone Levi, E. Macrory.
1867. Dundee	M. E. Grant-Duff, M.P.	Prof. Leone Levi, E. Macrory, A. J. Warden.
1868. Norwich	Samuel Brown	Rev. W. C. Davie, Prof. Leone Levi.
1869. Exeter	Rt.Hon. Sir Stafford H. Northcote, Bart., C.B., M.P.	E. Macrory, F. Purdy, C. T. D. Acland.
1870. Liverpool...	Prof. W. Stanley Jevons, M.A.	Chas. R. Dudley Baxter, E. Macrory, J. Miles Moss.
1871. Edinburgh	Rt. Hon. Lord Neaves	J. G. Fitch, James Meikle.
1872 Brighton ...	Prof. Henry Fawcett, M.P. ...	J. G. Fitch, Barclay Phillips.
1873. Bradford ...	Rt. Hon. W. E. Forster, M.P.	J. G. Fitch, Swire Smith.
1874. Belfast......	Lord O'Hagan	Prof. Donnell, F. P. Fellows, Hans MacMordie.
1875. Bristol	James Heywood, M.A., F.R.S., Pres. S.S.	F. P. Fellows, T. G. P. Hallett, E. Macrory.
1876. Glasgow ...	Sir George Campbell, K.C.S.I., M.P.	A. M'Neel Caird, T. G. P. Hallett, Dr. W. Neilson Hancock, Dr. W. Jack.
1877. Plymouth...	Rt. Hon. the Earl Fortescue	W. F. Collier, P. Hallett, J. T. Pim.
1878. Dublin	Prof. J. K. Ingram, LL.D. ...	W. J. Hancock, C. Molloy, J. T. Pim.
1879. Sheffield ...	G. Shaw Lefevre, M.P., Pres. S.S.	Prof. Adamson, R. E. Leader, C. Molloy.
1880. Swansea ...	G. W. Hastings, M.P.	N. A. Humphreys, C. Molloy.
1881. York	Rt. Hon. M. E. Grant-Duff, M.A., F.R.S.	C. Molloy, W. W. Morrell, J. F. Moss.
1882. Southampton.	Rt. Hon. G. Sclater-Booth, M.P., F.R.S.	G. Baden-Powell, Prof. H. S. Foxwell, A. Milnes, C. Molloy.
1883. Southport	R. H. Inglis Palgrave, F.R.S.	Rev. W. Cunningham, Prof. H. S. Foxwell, J. N. Keynes, C. Molloy.
1884. Montreal ...	Sir Richard Temple, Bart., G.C.S.I., C.I.E., F.R.G.S.	Prof. H. S. Foxwell, J. S. McLennan, Prof. J. Watson.
1885. Aberdeen...	Prof. H. Sidgwick, LL.D., Litt.D.	Rev. W. Cunningham, Prof. H. S. Foxwell, C. McCombie, J. F. Moss.
1886. Birmingham.	J. B. Martin, M.A., F.S.S. ...	F. F. Barham, Rev. W. Cunningham, Prof. H. S. Foxwell, J. F. Moss.
1887. Manchester	Robert Giffen, LL.D., V.P.S.S.	Rev. W. Cunningham, F. Y. Edgeworth, T. H. Elliott, C. Hughes, J. E. C. Munro, G. H. Sargant.
1888. Bath	Rt. Hon. Lord Bramwell, LL.D., F.R.S.	Prof. F. Y. Edgeworth, T. H. Elliott, H. S. Foxwell, L. L. F. R. Price.
1889. Newcastle-upon-Tyne	Prof. F. Y. Edgeworth, M.A., F.S.S.	Rev. Dr. Cunningham, T. H. Elliott, F. B. Jevons, L. L. F. R. Price.
1890. Leeds	Prof. A. Marshall, M.A., F.S.S.	W. A. Brigg, Rev. Dr. Cunningham, T. H. Elliott, Prof. J. E. C. Munro, L. L. F. R. Price.
1891 Cardiff. ..	Prof. W. Cunningham, D.D., D.Sc., F.S.S.	Prof. J. Brough, E. Cannan, Prof. E. C. K. Gonner, H. Ll. Smith, Prof. W. R. Sorley.

Date and Place	Presidents	Secretaries
1892. Edinburgh	Hon. Sir C. W. Fremantle, K.C.B.	Prof. J. Brough, J. R. Findlay, Prof. E. C. K. Gonner, H. Higgs, L. L. F. R. Price.
1893. Nottingham	Prof. J. S. Nicholson, D.Sc., F.S.S.	Prof. E C. K. Gonner, H. de B. Gibbins, J. A. H. Green, H. Higgs, L. L. F. R. Price.
1894. Oxford......	Prof. C. F. Bastable, M.A., F.S.S.	E. Cannan, Prof. E. C. K. Gonner, W. A. S. Hewins, H. Higgs.
1895. Ipswich ...	L. L. Price, M.A.	E. Cannan, Prof. E. C. K. Gonner, H. Higgs.
1896. Liverpool...	Rt. Hon. L. Courtney, M.P....	E. Cannan, Prof. E. C. K. Gonner, W. A. S. Hewins, H. Higgs.
1897. Toronto ...	Prof. E. C. K. Gonner, M.A.	E. Cannan, H. Higgs, Prof. A. Shortt.
1898. Bristol	J. Bonar, M.A., LL.D.........	E. Cannan, Prof. A. W. Flux, H. Higgs, W. E. Tanner.
1899. Dover	H. Higgs, LL.B.	A. L. Bowley, E. Cannan, Prof. A. W. Flux, Rev. G. Sarson.
1900. Bradford ...	Major P. G. Craigie, V.P.S.S.	A. L. Bowley, E. Cannan, S. J. Chapman, F. Hooper.
1901. Glasgow ...	Sir R. Giffen, K.C.B., F.R.S.	W. W. Blackie, A. L. Bowley, E. Cannan, S. J. Chapman.
1902. Belfast ...	E. Cannan, M.A., LL.D.	A. L. Bowley, Prof. S. J. Chapman, Dr. A. Duffin.
1903. Southport	E. W. Brabrook, C.B.	A. L. Bowley, Prof. S. J. Chapman, Dr. B. W. Ginsburg, G. Lloyd.
1904. Cambridge	Prof. Wm. Smart, LL.D.	J. E. Bidwell, A. L. Bowley, Prof. S. J. Chapman, Dr. B. W. Ginsburg.
1905. SouthAfrica	Rev. W. Cunningham, D.D., D.Sc.	R. à Ababrelton, A. L. Bowley, Prof. H. E. S. Fremantle, H. O. Meredith.
1906. York.........	A. L. Bowley, M.A.	Prof. S. J. Chapman, D. H. Macgregor, H. O. Meredith, B. S. Rowntree.
1907. Leicester...	Prof. W. J. Ashley, M.A.......	Prof. S. J. Chapman, D. H. Macgregor, H. O. Meredith, T. S. Taylor.
1908. Dublin......	W. M. Acworth, M.A.	W. G. S. Adams, Prof. S. J. Chapman, Prof. D. H. Macgregor, H. O. Meredith.
	Sub-section of Agriculture—Rt. Hon. Sir H. Plunkett.	A. D. Hall, Prof. J. Percival, J. H. Priestley, Prof. J. Wilson.
1909. Winnipeg...	Prof. S. J. Chapman, M.A. ...	Prof. A. B. Clark, Dr. W. A. Manahan, Dr. W. R. Scott.
1910. Sheffield ...	Sir H. Llewellyn Smith, K.C.B., M.A.	C. R. Fay, H. O. Meredith, Dr. W. R. Scott, R. Wilson.

SECTION G.—MECHANICAL SCIENCE.

1836. Bristol......	Davies Gilbert, D.C.L., F.R.S.	T. G. Bunt, G. T. Clark, W. West.
1837. Liverpool...	Rev. Dr. Robinson	Charles Vignoles, Thomas Webster.
1838. Newcastle	Charles Babbage, F.R.S.......	R. Hawthorn, C. Vignoles, T. Webster.
1839. Birmingham.	Prof. Willis, F.R.S., and Robt. Stephenson.	W. Carpmael, William Hawkes, T. Webster.
1840. Glasgow	Sir John Robinson	J. Scott Russell, J. Thomson, J. Tod, C. Vignoles.
1841. Plymouth...	John Taylor, F.R.S.	Henry Chatfield, Thomas Webster.
1842. Manchester	Rev. Prof. Willis, F.R.S.	J. F. Bateman, J. Scott Russell, J. Thomson, Charles Vignoles.
1843. Cork	Prof. J. Macneill, M.R.I.A....	James Thomson, Robert Mallet.
1844. York	John Taylor, F.R.S.	Charles Vignoles, Thomas Webster.
1845. Cambridge	George Rennie, F.R.S.........	Rev. W. T. Kingsley.
1846. Southampton.	Rev. Prof. Willis, M.A., F.R.S.	William Betts, jun., Charles Manby.

Date and Place	Presidents	Secretaries
1847. Oxford......	Rev. Prof. Walker, M.A., F.R.S.	J. Glynn, R. A. Le Mesurier.
1848. Swansea ...	Rev. Prof. Walker, M.A., F.R.S.	R. A. Le Mesurier, W. P. Struvé.
1849. Birmingham	Robt. Stephenson, M.P., F.R.S.	Charles Manby, W. P. Marshall.
1850. Edinburgh	Rev. R. Robinson	Dr. Lees, David Stephenson.
1851. Ipswich ...	William Cubitt, F.R.S..........	John Head, Charles Manby.
1852. Belfast......	John Walker, C.E., LL.D., F.R.S.	John F. Bateman, C. B. Hancock, Charles Manby, James Thomson.
1853. Hull	William Fairbairn, F.R.S. ...	J. Oldham, J. Thomson, W. S. Ward.
1854. Liverpool...	John Scott Russell, F.R.S. ...	J. Grantham, J. Oldham, J. Thomson.
1855. Glasgow ...	W. J. M. Rankine, F.R.S. ...	L. Hill, W. Ramsay, J. Thomson.
1856. Cheltenham	George Rennie, F.R.S.	C. Atherton, B. Jones, H. M. Jeffery.
1857. Dublin......	Rt. Hon. the Earl of Rosse, F.R.S.	Prof. Downing, W.T. Doyne, A. Tate, James Thomson, Henry Wright.
1858. Leeds	William Fairbairn, F.R.S. ...	J. C. Dennis, J. Dixon, H. Wright.
1859. Aberdeen...	Rev. Prof. Willis, M.A., F.R.S.	R. Abernethy, P. Le Neve Foster, H. Wright.
1860. Oxford	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	P. Le Neve Foster, Rev. F. Harrison, Henry Wright.
1861. Manchester	J. F. Bateman, C.E., F.R.S....	P. Le Neve Foster, John Robinson, H. Wright.
1862. Cambridge	William Fairbairn, F.R.S. ...	W. M. Fawcett, P. Le Neve Foster.
1863. Newcastle	Rev. Prof. Willis, M.A., F.R.S.	P. Le Neve Foster, P. Westmacott, J. F. Spencer
1864. Bath	J. Hawkshaw, F.R.S.	P. Le Neve Foster, Robert Pitt.
1865. Birmingham.	Sir W. G. Armstrong, LL.D., F.R.S.	P. Le Neve Foster, Henry Lea, W. P. Marshall, Walter May.
1866. Nottingham	Thomas Hawksley, V.P. Inst. C.E., F.G.S.	P. Le Neve Foster, J. F. Iselin, M. O. Tarbotton.
1867. Dundee......	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	P. Le Neve Foster, John P. Smith, W. W. Urquhart.
1868. Norwich ...	G. P. Bidder, C.E., F.R.G.S.	P. Le Neve Foster, J. F. Iselin, C. Manby, W. Smith.
1869. Exeter	C. W. Siemens, F.R.S..........	P. Le Neve Foster, H. Bauerman.
1870. Liverpool...	Chas. B Vignoles, C.E., F.R.S.	H. Bauerman, P. Le Neve Foster, T. King, J. N. Shoolbred.
1871. Edinburgh	Prof. Fleeming Jenkin, F.R.S.	H. Bauerman, A. Leslie, J. P. Smith.
1872. Brighton ...	F. J. Bramwell, C.E.	H. M. Brunel, P. Le Neve Foster, J. G. Gamble, J. N. Shoolbred.
1873. Bradford ...	W. H. Barlow, F.R.S.	C. Barlow, H. Bauerman, E.H. Carbutt, J. C. Hawkshaw, J. N. Shoolbred.
1874. Belfast......	Prof. James Thomson, LL.D., C.E., F.R.S.E.	A. T. Atchison, J. N. Shoolbred, John Smyth, jun.
1875. Bristol	W. Froude, C.E., M.A., F.R.S.	W. R. Browne, H. M. Brunel, J. G. Gamble, J. N. Shoolbred.
1876. Glasgow ...	C. W. Merrifield, F.R.S.	W. Bottomley, jun., W. J. Millar, J. N. Shoolbred, J. P. Smith.
1877. Plymouth...	Edward Woods, C.E.	A. T. Atchison, Dr. Merrifield, J. N. Shoolbred.
1878. Dublin	Edward Easton, C.E.	A. T. Atchison, R. G. Symes, H. T. Wood.
1879. Sheffield ...	J. Robinson, Pres. Inst. Mech. Eng.	A. T. Atchison, Emerson Bainbridge, H. T. Wood.
1880. Swansea ...	J. Abernethy, F.R.S.E..........	A. T. Atchison, H. T. Wood.
1881. York.........	Sir W. G. Armstrong, C.B., LL.D., D.C.L., F.R.S.	A. T. Atchison, J. F. Stephenson, H. T. Wood.
1882. Southampton.	John Fowler, C.E., F.G.S. ...	A. T. Atchison, F. Churton, H. T. Wood.
1883. Southport...	J. Brunlees, Pres. Inst. C.E. ...	A. T. Atchison, E. Rigg, H. T. Wood.
1884. Montreal ...	Sir F. J. Bramwell, F.R.S., V.P. Inst. C.E.	A. T. Atchison, W. B. Dawson, J. Kennedy, H. T. Wood.

Date and Place	Presidents	Secretaries
1885. Aberdeen...	B. Baker, M.Inst.C.E.	A. T. Atchison, F. G. Ogilvie, E. Rigg, J. N. Shoolbred.
1886. Birmingham.	Sir J. N. Douglass, M.Inst. C.E.	C. W. Cooke, J. Kenward, W. B. Marshall, E. Rigg.
1887. Manchester	Prof. Osborne Reynolds, M.A., LL.D., F.R.S.	C. F. Budenberg, W. B. Marshall, E. Rigg.
1888. Bath.........	W. H. Preece, F.R.S., M.Inst.C.E.	C. W. Cooke, W. B. Marshall, E. Rigg, P. K. Stothert.
1889. Newcastle-upon-Tyne.	W. Anderson, M.Inst.C.E. ...	C. W. Cooke, W. B. Marshall, Hon. C. A. Parsons, E. Rigg.
1890. Leeds	Capt. A. Noble, C.B., F.R.S., F.R.A.S.	E. K. Clark, C. W. Cooke, W. B. Marshall, E. Rigg.
1891. Cardiff.....	T. Forster Brown, M.Inst.C.E.	C. W. Cooke, Prof. A. C. Elliott, W. B. Marshall, E. Rigg.
1892. Edinburgh	Prof. W. C. Unwin, F.R.S., M.Inst.C.E.	C. W. Cooke, W. B. Marshall, W. C. Popplewell, E. Rigg.
1893. Nottingham	Jeremiah Head, M.Inst C.E., F.C.S.	C. W. Cooke, W. B. Marshall, E. Rigg, H. Talbot.
1894. Oxford......	Prof. A. B. W. Kennedy, F.R.S., M.Inst.C.E.	Prof. T. Hudson Beare, C. W. Cooke, W. B. Marshall, Rev. F. J. Smith.
1895. Ipswich ...	Prof. L. F. Vernon-Harcourt, M.A., M.Inst.C.E.	Prof. T. Hudson Beare, C. W. Cooke. W. B. Marshall, P. G. M. Stoney.
1896. Liverpool...	Sir Douglas Fox, V.P.Inst.C.E.	Prof. T. Hudson Beare, C. W. Cooke, S. Dunkerley, W. B. Marshall.
1897. Toronto ...	G. F. Deacon, M.Inst.C.E. ...	Prof. T. Hudson Beare, Prof. Callendar, W. A. Price.
1898. Bristol......	Sir J. Wolfe-Barry, K.C.B., F.R.S.	Prof. T. H. Beare, Prof. J. Munro, H. W. Pearson, W. A. Price.
1899. Dover	Sir W. White, K.C.B., F.R.S.	Prof. T. H. Beare, W. A. Price, H. E. Stilgoe.
1900. Bradford[1]	Sir Alex. R. Binnie, M.Inst. C.E.	Prof. T. H. Beare, C. F. Charnock, Prof. S. Dunkerley, W. A. Price.

SECTION G.—ENGINEERING.

1901. Glasgow ...	R. E. Crompton, M.Inst.C.E.	H. Bamford, W.E. Dalby, W. A. Price.
1902. Belfast ...	Prof. J. Perry, F.R.S.	M. Barr, W. A. Price, J. Wylie.
1903. Southport	C. Hawksley, M.Inst.C.E. ...	Prof. W. E. Dalby, W. T. Maccall, W. A. Price.
1904. Cambridge	Hon. C. A. Parsons, F.R.S. ...	J. B. Peace, W. T. Maccall, W. A. Price.
1905. SouthAfrica	Col. Sir C. Scott-Moncrieff, G.C.S.I., K.C.M.G., R.E.	W. T. Maccall, W. B. Marshall, Prof. H. Payne, E. Williams.
1906. York.........	J. A. Ewing, F.R.S.	W. T. Maccall, W. A. Price, J. Triffit.
1907. Leicester...	Prof. Silvanus P. Thompson, F.R.S.	Prof. E. G. Coker, A. C. Harris, W. A. Price, H. E. Wimperis.
1908. Dublin	Dugald Clerk, F.R.S.	Prof. E. G. Coker, Dr. W. E. Lilly, W. A. Price, H. E. Wimperis.
1909. Winnipeg...	Sir W. H. White, K.C.B., F.R.S.	E. E. Brydone-Jack, Prof. E. G. Coker, Prof. E. W. Marchant, W. A. Price.
1910. Sheffield ..	Prof. W. E. Dalby, M.A., M.Inst.C.E.	F. Boulden, Prof. E. G. Coker, A. A. Rowse, H. E. Wimperis.

SECTION H.—ANTHROPOLOGY.

1884. Montreal...	E. B. Tylor, D.C.L., F.R.S. ...	G. W. Bloxam, W. Hurst.
1885. Aberdeen...	Francis Galton, M.A., F.R.S.	G. W. Bloxam, Dr. J. G. Garson, W. Hurst, Dr. A. Macgregor.
1886. Birmingham.	Sir G. Campbell, K.C.S.I., M.P., D.C.L., F.R.G.S.	G. W. Bloxam, Dr. J. G. Garson, W. Hurst, Dr. R. Saundby.

[1] The title of Section G was changed to Engineering.

Date and Place	Presidents	Secretaries
1887. Manchester	Prof. A. H. Sayce, M.A.	G. W. Bloxam, Dr. J. G. Garson, Dr. A. M. Paterson
1888. Bath.........	Lieut.-General Pitt-Rivers, D.C.L., F.R.S.	G. W. Bloxam, Dr. J. G. Garson, J. Harris Stone.
1889. Newcastle-upon-Tyne	Prof. Sir W. Turner, M.B., LL.D., F.R.S.	G. W. Bloxam, Dr. J. G. Garson, Dr. R. Morison, Dr. R. Howden.
1890. Leeds	Dr. J. Evans, Treas. R.S., F.S.A., F.L.S., F.G.S.	G. W. Bloxam, Dr. C. M. Chadwick, Dr. J. G. Garson.
1891. Cardiff......	Prof. F. Max Müller, M.A. ...	G. W. Bloxam, Prof. R. Howden, H. Ling Roth, E. Seward.
1892. Edinburgh	Prof. A. Macalister, M.A., M.D., F.R.S.	G. W. Bloxam, Dr. D. Hepburn, Prof. R. Howden, H. Ling Roth.
1893. Nottingham	Dr. R. Munro, M.A., F.R.S.E.	G. W. Bloxam, Rev. T. W. Davies, Prof. R. Howden, F. B. Jevons, J. L. Myres.
1894. Oxford......	Sir W. H. Flower, K.C.B., F.R.S.	H. Balfour, Dr. J. G. Garson, H. Ling Roth.
1895. Ipswich ...	Prof. W. M. Flinders Petrie, D.C.L.	J. L. Myres, Rev. J. J. Raven, H. Ling Roth.
1896. Liverpool...	Arthur J. Evans, F.S.A.	Prof. A. C. Haddon, J. L. Myres, Prof. A. M. Paterson.
1897. Toronto ...	Sir W. Turner, F.R.S.	A. F. Chamberlain, H. O. Forbes, Prof. A. C. Haddon, J. L. Myres.
1898. Bristol......	E. W. Brabrook, C.B.	H. Balfour, J. L. Myres, G. Parker.
1899. Dover	C. H. Read, F.S.A.	H. Balfour, W. H. East, Prof. A. C. Haddon, J. L. Myres.
1900. Bradford...	Prof. John Rhys, M.A.........	Rev. E. Armitage, H. Balfour, W. Crooke, J. L. Myres.
1901. Glasgow ...	Prof. D. J. Cunningham, F.R.S.	W. Crooke, Prof. A. F. Dixon, J. F. Gemmill, J. L. Myres.
1902. Belfast ...	Dr. A. C. Haddon, F.R.S. ...	R. Campbell, Prof. A. F. Dixon, J. L. Myres.
1903. Southport...	Prof. J. Symington, F.R.S....	E. N. Fallaize, H. S. Kingsford, E. M. Littler, J. L. Myres.
1904. Cambridge	H. Balfour, M.A.	W. L. H. Duckworth, E. N. Fallaize, H. S. Kingsford, J. L. Myres.
1905. SouthAfrica	Dr. A. C. Haddon, F.R.S. ...	A. R. Brown, A. von Dessauer, E. S. Hartland.
1906. York.........	E. Sidney Hartland, F.S.A....	Dr. G. A. Auden, E. N. Fallaize, H. S. Kingsford, Dr. F. C. Shrubsall.
1907. Leicester...	D. G. Hogarth, M.A............	C. J. Billson, E. N. Fallaize, H. S. Kingsford, Dr. F. C. Shrubsall.
1908. Dublin......	Prof. W. Ridgeway, M.A. ...	E. N. Fallaize, H. S. Kingsford, Dr. F. C. Shrubsall, L. E. Steele.
1909. Winnipeg...	Prof. J. L. Myres, M.A.	H. S. Kingsford, Prof. C. J. Patten, Dr. F. C. Shrubsall.
1910. Sheffield ...	W. Crooke, B.A.	E. N. Fallaize, H. S. Kingsford, Prof. C. J. Patten, Dr. F. C. Shrubsall.

SECTION I.—PHYSIOLOGY (including Experimental Pathology and Experimental Psychology).

1894. Oxford......	Prof. E. A. Schäfer, F.R.S., M.R.C.S.	Prof. F. Gotch, Dr. J. S. Haldane, M. S. Pembrey.
1896. Liverpool...	Dr. W. H. Gaskell, F.R.S. ...	Prof. R. Boyce, Prof. C. S. Sherrington.
1897. Toronto ...	Prof. Michael Foster, F.R.S.	Prof. R. Boyce, Prof. C. S. Sherrington, Dr. L. E. Shore.
1899. Dover	J. N. Langley, F.R.S.	Dr. Howden, Dr. L. E. Shore, Dr. E. H. Starling.

Date and Place	Presidents	Secretaries
1901. Glasgow ...	Prof. J. G. McKendrick, F.R.S.	W. B. Brodie, W. A. Osborne, Prof. W. H. Thompson.
1902. Belfast ...	Prof. W. D. Halliburton, F.R.S.	J. Barcroft, Dr. W. A. Osborne, Dr. C. Shaw.
1904. Cambridge	Prof. C. S. Sherrington, F.R.S.	J. Barcroft, Prof. T. G. Brodie, Dr. L. E. Shore.
1905. SouthAfrica	Col. D. Bruce, C.B., F.R.S. ...	J. Barcroft, Dr. Baumann, Dr. Mackenzie, Dr. G. W. Robertson, Dr. Stanwell.
1906. York.........	Prof. F. Gotch, F.R.S.	J. Barcroft, Dr. J. M. Hamill, Prof. J. S. Macdonald, Dr. D. S. Long.
1907. Leicester ...	Dr. A. D. Waller, F.R.S.	Dr. N. H. Alcock, J. Barcroft, Prof. J. S. Macdonald, Dr. A. Warner.
1908. Dublin	Dr. J. Scott Haldane, F.R.S.	Prof. D J. Coffey, Dr. P. T. Herring, Prof. J. S. Macdonald, Dr. H. E. Roaf.
1909. Winnipeg...	Prof. E. H. Starling, F.R.S....	Dr. N. H. Alcock, Prof. P. T. Herring, Dr. W. Webster.
1910. Sheffield ...	Prof. A. B. Macallum, F.R.S.	Dr. H. G. M. Henry, Keith Lucas, Dr. H. E. Roaf, Dr. J. Tait.

SECTION K.—BOTANY.

1895. Ipswich ...	W. T. Thiselton-Dyer, F.R.S.	A. C. Seward, Prof. F. E. Weiss.
1896. Liverpool...	Dr. D. H. Scott, F.R.S.	Prof. Harvey Gibson, A. C. Seward, Prof. F. E. Weiss.
1897. Toronto ...	Prof. Marshall Ward, F.R.S.	Prof. J. B. Farmer, E. C. Jeffrey, A. C. Seward, Prof. F. E. Weiss.
1898. Bristol......	Prof. F. O. Bower, F.R.S. ...	A. C. Seward, H. Wager, J. W. White.
1899. Dover	Sir George King, F.R.S.	G. Dowker, A. C. Seward, H. Wager.
1900. Bradford ...	Prof. S. H. Vines, F.R.S.......	A. C. Seward, H. Wager, W. West.
1901. Glasgow ...	Prof. I. B. Balfour, F.R.S. ...	D. T. Gwynne-Vaughan, G. F. Scott-Elliot, A. C. Seward, H. Wager.
1902. Belfast ...	Prof. J. R. Green, F.R.S.......	A. G. Tansley, Rev. C. H. Waddell, H. Wager, R. H. Yapp.
1903. Southport	A. C. Seward, F.R.S.	H. Ball, A. G. Tansley, H. Wager, R. H. Yapp.
1904. Cambridge	Francis Darwin, F.R.S. ...... *Sub-section of Agriculture*—Dr. W. Somerville.	Dr. F. F. Blackman, A. G. Tansley, H. Wager, T. B. Wood, R. H. Yapp.
1905. SouthAfrica	Harold Wager, F.R.S.	R. P. Gregory, Dr. Marloth, Prof. Pearson, Prof. R. H. Yapp.
1906. York.........	Prof. F. W. Oliver, F.R.S. ...	Dr. A. Burtt, R. P. Gregory, Prof. A. G. Tansley, Prof. R. H. Yapp.
1907. Leicester ...	Prof. J. B. Farmer, F.R.S. ...	W. Bell, R. P. Gregory, Prof. A. G. Tansley, Prof. R. H. Yapp.
1908. Dublin	Dr. F. F. Blackman, F.R.S....	Prof. H. H. Dixon, R. P. Gregory, A. G. Tansley, Prof. R. H. Yapp.
1909. Winnipeg...	Lieut.-Col. D. Prain, C.I.E., F.R.S.	Prof. A. H. R. Buller, Prof. D. T. Gwynne-Vaughan, Prof. R. H. Yapp.
	Sub-section of Agriculture—Major P. G. Craigie, C.B.	W. J. Black, Dr. E. J. Russell, Prof. J. Wilson.
1910. Sheffield ...	Prof. J. W. H. Trail, F.R.S.	B. H. Bentley, R. P. Gregory, Prof. D. T. Gwynne-Vaughan, Prof. R. H. Yapp.

SECTION L.—EDUCATIONAL SCIENCE.

1901. Glasgow ...	Sir John E. Gorst, F.R.S. ...	R. A. Gregory, W. M. Heller, R. Y. Howie, C. W. Kimmins, Prof H. L. Withers.

Date and Place	Presidents	Secretaries
1902. Belfast ...	Prof. H. E. Armstrong, F.R.S.	Prof. R. A. Gregory, W. M. Heller, R. M. Jones, Dr. C. W. Kimmins, Prof. H. L. Withers.
1903. Southport ..	Sir W. de W. Abney, K.C.B., F.R.S.	Prof. R. A. Gregory, W. M. Heller, Dr. C. W. Kimmins, Dr. H. L. Snape.
1904. Cambridge	Bishop of Hereford, D.D. ...	J. H. Flather, Prof. R. A. Gregory, W. M. Heller, Dr. C. W. Kimmins.
1905. SouthAfrica	Prof. Sir R. C. Jebb, D.C.L., M.P.	A. D. Hall, Prof. Hele-Shaw, Dr. C. W. Kimmins, J. R. Whitton.
1906. York.........	Prof. M. E. Sadler, LL.D. ...	Prof. R. A. Gregory, W. M. Heller, Hugh Richardson.
1907. Leicester ...	Sir Philip Magnus, M.P.	W. D. Eggar, Prof. R. A. Gregory, J. S. Laver, Hugh Richardson.
1908. Dublin	Prof. L. C. Miall, F.R.S.	Prof. E. P. Culverwell, W. D. Eggar, George Fletcher, Prof. R. A. Gregory, Hugh Richardson.
1909. Winnipeg...	Rev. H. B. Gray, D.D.	W. D. Eggar, R. Fletcher, J. L. Holland, Hugh Richardson.
1910. Sheffield ...	Principal H. A. Miers, F.R.S.	A. J. Arnold, W. D. Eggar, J. L. Holland, Hugh Richardson.

CHAIRMEN AND SECRETARIES OF THE CONFERENCES OF DELEGATES OF CORRESPONDING SOCIETIES.

Date and Place	Chairmen	Secretaries
1885. Aberdeen...	Francis Galton, F.R.S..........	Prof. Meldola.
1886. Birmingham	Prof. A. W. Williamson, F.R.S.	Prof. Meldola, F.R.S.
1887. Manchester	Prof. W. Boyd Dawkins, F.R.S.	Prof. Meldola, F.R.S.
1888. Bath.........	John Evans, F.R.S.	Prof. Meldola, F.R.S.
1889. Newcastle-upon-Tyne	Francis Galton, F.R.S..........	Prof. G. A. Lebour.
1890. Leeds	G. J. Symons, F.R.S.	Prof. Meldola, F.R.S.
1891. Cardiff	G. J. Symons, F.R.S.	Prof. Meldola, F.R.S.
1892. Edinburgh	Prof. Meldola, F.R.S.	T. V. Holmes.
1893. Nottingham	Dr. J. G. Garson	T. V. Holmes.
1894. Oxford	Prof. Meldola, F.R.S.	T. V. Holmes.
1895. Ipswich ...	G. J. Symons, F.R.S.	T. V. Holmes.
1896. Liverpool...	Dr. J. G. Garson	T. V. Holmes.
1897. Toronto ...	Prof. Meldola, F.R.S.	J. Hopkinson.
1898. Bristol	W. Whitaker, F.R.S.	T. V. Holmes.
1899. Dover	Rev. T. R. R. Stebbing, F.R.S.	T. V. Holmes.
1900. Bradford ...	Prof. E. B. Poulton, F.R.S. ...	T. V. Holmes.
1901. Glasgow ...	F. W. Rudler, F.G.S.	Dr. J. G. Garson, A. Somerville.
1902 Belfast......	Prof. W. W. Watts, F.G.S. ...	E. J. Bles.
1903. Southport ..	W. Whitaker, F.R.S.	F. W. Rudler.
1904. Cambridge	Prof. E. H. Griffiths, F.R.S.	F. W. Rudler.
1905. London ...	Dr. A. Smith Woodward, F.R.S.	F. W. Rudler.
1906. York.........	Sir Edward Brabrook, C.B....	F. W. Rudler.
1907. Leicester ...	H. J. Mackinder, M.A..........	F. W. Rudler, I.S.O.
1908. Dublin	Prof. H. A. Miers, F.R.S.......	W. P. D. Stebbing.
1909. London ...	Dr. A. C. Haddon, F.R.S. ...	W. P. D. Stebbing.
1910. Sheffield ...	Dr. Tempest Anderson.........	W. P. D. Stebbing.

EVENING DISCOURSES.

Date and Place	Lecturers	Subject of Discourse
1842. Manchester	Charles Vignoles, F.R.S......	The Principles and Construction of Atmospheric Railways.
	Sir M. I. Brunel	The Thames Tunnel.
	R. I. Murchison..................	The Geology of Russia.
1843. Cork	Prof. Owen, M.D., F.R.S.......	The Dinornis of New Zealand.
	Prof. E. Forbes, F.R.S..........	The Distribution of Animal Life in the Ægean Sea.
	Dr. Robinson	The Earl of Rosse's Telescope.
1844. York	Charles Lyell, F.R.S.	Geology of North America.
	Dr. Falconer, F.R.S.............	The Gigantic Tortoise of the Siwalik Hills in India.
1845. Cambridge	G.B.Airy,F.R.S.,Astron.Royal	Progress of Terrestrial Magnetism.
	R. I. Murchison, F.R.S.	Geology of Russia.
1846. Southampton.	Prof. Owen, M.D., F.R.S. ...	Fossil Mammalia of the British Isles.
	Charles Lyell, F.R.S.	Valley and Delta of the Mississippi.
	W. R. Grove, F.R.S............	Properties of the Explosive Substance discovered by Dr. Schönbein; also some Researches of his own on the Decomposition of Water by Heat.
1847. Oxford......	Rev. Prof. B. Powell, F.R.S.	Shooting Stars.
	Prof. M. Faraday, F.R.S.......	Magnetic and Diamagnetic Phenomena.
	Hugh E. Strickland, F.G.S....	The Dodo (*Didus ineptus*).
1848. Swansea ...	John Percy, M.D., F.R.S.......	Metallurgical Operations of Swansea and its Neighbourhood.
	W. Carpenter, M.D., F.R.S....	Recent Microscopical Discoveries.
1849. Birmingham.	Dr. Faraday, F.R.S.	Mr. Gassiot's Battery.
	Rev. Prof. Willis, M.A., F.R.S.	Transit of different Weights with varying Velocities on Railways.
1850. Edinburgh	Prof. J. H. Bennett, M.D., F.R.S.E.	Passage of the Blood through the minute vessels of Animals in connection with Nutrition.
	Dr. Mantell, F.R.S.	Extinct Birds of New Zealand.
1851. Ipswich ...	Prof. R. Owen, M.D., F.R.S.	Distinction between Plants and Animals, and their Changes of Form.
	G. B. Airy, F.R.S., Astronomer Royal	Total Solar Eclipse of July 28, 1851.
1852. Belfast......	Prof. G. G. Stokes, D.C.L., F.R.S.	Recent Discoveries in the properties of Light.
	Colonel Portlock, R.E., F.R.S.	Recent Discovery of Rock-salt at Carrickfergus, and geological and practical considerations connected with it.
1853. Hull	Prof. J. Phillips, LL.D., F.R.S., F.G.S.	Some peculiar Phenomena in the Geology and Physical Geography of Yorkshire.
	Robert Hunt, F.R.S.............	The present state of Photography.
1854. Liverpool...	Prof. R. Owen, M.D., F.R.S.	Anthropomorphous Apes.
	Col. E. Sabine, V.P.R.S.	Progress of Researches in Terrestrial Magnetism.
1855. Glasgow ...	Dr. W. B. Carpenter, F.R.S.	Characters of Species.
	Lieut.-Col. H. Rawlinson ...	Assyrian and Babylonian Antiquities and Ethnology.
1856. Cheltenham	Col. Sir H. Rawlinson	Recent Discoveries in Assyria and Babylonia, with the results of Cuneiform Research up to the present time.
	W. R. Grove, F.R.S............	Correlation of Physical Forces.

Date and Place	Lecturers	Subject of Discourse
1857. Dublin......	Prof. W. Thomson, F.R.S. ...	The Atlantic Telegraph.
	Rev. Dr. Livingstone, D.C.L.	Recent Discoveries in Africa.
1858. Leeds	Prof. J. Phillips, LL.D., F.R.S.	The Ironstones of Yorkshire.
	Prof. R. Owen, M.D., F.R.S.	The Fossil Mammalia of Australia.
1859. Aberdeen...	Sir R. I. Murchison, D.C.L....	The Geology of the Northern Highlands.
	Rev. Dr. Robinson, F.R.S. ...	Electrical Discharges in highly rarefied Media.
1860. Oxford......	Rev. Prof. Walker, F.R.S. ...	Physical Constitution of the Sun.
	Captain Sherard Osborn, R.N.	Arctic Discovery.
1861. Manchester	Prof. W. A. Miller, M.A., F.R.S.	Spectrum Analysis.
	G.B. Airy, F.R.S., Astron. Royal	The late Eclipse of the Sun.
1862. Cambridge	Prof. Tyndall, LL.D., F.R.S.	The Forms and Action of Water.
	Prof. Odling, F.R.S............	Organic Chemistry.
1863. Newcastle	Prof. Williamson, F.R.S......	The Chemistry of the Galvanic Battery considered in relation to Dynamics.
	James Glaisher, F.R.S.........	The Balloon Ascents made for the British Association.
1864. Bath.........	Prof. Roscoe, F.R.S............	The Chemical Action of Light.
	Dr. Livingstone, F.R.S.	Recent Travels in Africa.
1865. Birmingham.	J. Beete Jukes, F.R.S.........	Probabilities as to the position and extent of the Coal-measures beneath the red rocks of the Midland Counties.
1866. Nottingham	William Huggins, F.R.S......	The Results of Spectrum Analysis applied to Heavenly Bodies.
	Dr. J. D. Hooker, F.R.S.......	Insular Floras.
1867. Dundee......	Archibald Geikie, F.R.S......	The Geological Origin of the present Scenery of Scotland.
	Alexander Herschel, F.R.A.S.	The present state of Knowledge regarding Meteors and Meteorites.
1868. Norwich ...	J. Fergusson, F.R.S............	Archæology of the early Buddhist Monuments.
	Dr. W. Odling, F.R.S.........	Reverse Chemical Actions.
1869. Exeter	Prof. J. Phillips, LL.D., F.R.S.	Vesuvius.
	J. Norman Lockyer, F.R.S. ..	The Physical Constitution of the Stars and Nebulæ.
1870. Liverpool...	Prof. J. Tyndall, LL.D., F.R.S.	The Scientific Use of the Imagination.
	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	Stream-lines and Waves, in connection with Naval Architecture.
1871. Edinburgh	F. A. Abel, F.R.S..............	Some Recent Investigations and Applications of Explosive Agents.
	E. B. Tylor, F.R.S.	The Relation of Primitive to Modern Civilisation.
1872. Brighton ...	Prof. P. Martin Duncan, M.B., F.R.S.	Insect Metamorphosis.
	Prof. W. K. Clifford	The Aims and Instruments of Scientific Thought.
1873. Bradford ...	Prof. W. C. Williamson, F.R.S.	Coal and Coal Plants.
	Prof. Clerk Maxwell, F.R.S.	Molecules.
1874. Belfast......	Sir John Lubbock, Bart., M.P., F.R.S.	Common Wild Flowers considered in relation to Insects.
	Prof. Huxley, F.R.S.	The Hypothesis that Animals are Automata, and its History.
1875. Bristol	W. Spottiswoode, LL.D., F.R.S.	The Colours of Polarised Light.
	F. J. Bramwell, F.R.S.........	Railway Safety Appliances.
1876. Glasgow ...	Prof. Tait, F.R.S.E.	Force.
	Sir Wyville Thomson, F.R.S.	The 'Challenger Expedition.

Date and Place	Lecturers	Subject of Discourse
1877. Plymouth ...	W. Warington Smyth, M.A., F.R.S.	Physical Phenomena connected with the Mines of Cornwall and Devon.
	Prof. Odling, F.R.S.	The New Element, Gallium.
1878. Dublin	G. J. Romanes, F.L.S.	Animal Intelligence.
	Prof. Dewar, F.R.S.	Dissociation, or Modern Ideas of Chemical Action.
1879. Sheffield ...	W. Crookes, F.R.S.	Radiant Matter.
	Prof. E. Ray Lankester, F.R.S.	Degeneration.
1880. Swansea ...	Prof. W. Boyd Dawkins, F.R.S.	Primeval Man.
	Francis Galton, F.R.S.	Mental Imagery.
1881. York	Prof. Huxley, Sec. R.S.	The Rise and Progress of Palæontology.
	W. Spottiswoode, Pres. R.S.	The Electric Discharge: its Forms and its Functions.
1882. Southampton.	Prof. Sir Wm. Thomson, F.R.S.	Tides.
	Prof. H. N. Moseley, F.R.S.	Pelagic Life.
1883. Southport...	Prof. R. S. Ball, F.R.S.	Recent Researches on the Distance of the Sun.
	Prof. J. G. McKendrick.	Galvanic and Animal Electricity.
1884. Montreal...	Prof. O. J. Lodge, D.Sc.	Dust.
	Rev. W. H. Dallinger, F.R.S.	The Modern Microscope in Researches on the Least and Lowest Forms of Life.
1885. Aberdeen...	Prof. W. G. Adams, F.R.S.	The Electric Light and Atmospheric Absorption.
	John Murray, F.R.S.E.	The Great Ocean Basins.
1886. Birmingham.	A. W. Rücker, M.A., F.R.S.	Soap Bubbles.
	Prof. W. Rutherford, M.D.	The Sense of Hearing.
1887. Manchester	Prof. H. B. Dixon, F.R.S.	The Rate of Explosions in Gases.
	Col. Sir F. de Winton	Explorations in Central Africa.
1888. Bath	Prof. W. E. Ayrton, F.R.S.	The Electrical Transmission of Power
	Prof. T. G. Bonney, D.Sc., F.R.S.	The Foundation Stones of the Earth's Crust.
1889. Newcastle-upon-Tyne	Prof. W. C. Roberts-Austen, F.R.S.	The Hardening and Tempering of Steel.
	Walter Gardiner, M.A.	How Plants maintain themselves in the Struggle for Existence.
1890. Leeds	E. B. Poulton, M.A., F.R.S.	Mimicry.
	Prof. C. Vernon Boys, F.R.S.	Quartz Fibres and their Applications.
1891. Cardiff	Prof. L. C. Miall, F.L.S., F.G.S.	Some Difficulties in the Life of Aquatic Insects.
	Prof. A. W. Rücker, M.A., F.R.S.	Electrical Stress.
1892. Edinburgh	Prof. A. M. Marshall, F.R.S.	Pedigrees.
	Prof. J. A. Ewing, M.A., F.R.S.	Magnetic Induction.
1893. Nottingham	Prof. A. Smithells, B.Sc.	Flame.
	Prof. Victor Horsley, F.R.S.	The Discovery of the Physiology of the Nervous System.
1894. Oxford......	J. W. Gregory, D.Sc., F.G.S.	Experiences and Prospects of African Exploration.
	Prof. J. Shield Nicholson, M.A.	Historical Progress and Ideal Socialism.
1895. Ipswich ...	Prof. S. P. Thompson, F.R.S.	Magnetism in Rotation.
	Prof. Percy F. Frankland, F.R.S.	The Work of Pasteur and its various Developments.
1896. Liverpool...	Dr. F. Elgar, F.R.S.	Safety in Ships.
	Prof. Flinders Petrie, D.C.L.	Man before Writing.
1897. Toronto ...	Prof. W. C. Roberts-Austen, F.R.S.	Canada's Metals.
	J. Milne, F.R.S.	Earthquakes and Volcanoes.

Date and Place	Lecturers	Subject of Discourse
1898. Bristol......	Prof. W. J. Sollas, F.R.S.	Funafuti: the Study of a Coral Island.
	Herbert Jackson	Phosphorescence.
1899. Dover	Prof. Charles Richet...........	La vibration nerveuse.
	Prof. J. Fleming, F.R.S.	The Centenary of the Electric Current.
1900. Bradford ...	Prof. F. Gotch, F.R.S..........	Animal Electricity.
	Prof. W. Stroud.	Range Finders.
1901. Glasgow ...	Prof. W. Ramsay, F.R.S	The Inert Constituents of the Atmosphere.
	Francis Darwin, F.R.S.	The Movements of Plants.
1902. Belfast ...	Prof. J. J. Thomson, F.R.S....	Becquerel Rays and Radio-activity.
	Prof. W. F. R. Weldon, F.R.S.	Inheritance.
1903. Southport...	Dr. R. Munro	Man as Artist and Sportsman in the Palæolithic Period.
	Dr. A. Rowe	The Old Chalk Sea, and some of its Teachings.
1904. Cambridge	Prof. G. H. Darwin, F.R.S....	Ripple-Marks and Sand-Dunes.
	Prof. H. F. Osborn	Palæontological Discoveries in the Rocky Mountains.
1905. South Africa:		
Cape Town ...	Prof. E. B. Poulton, F.R.S. ...	W. J. Burchell's Discoveries in South Africa.
	C. Vernon Boys, F.R.S.	Some Surface Actions of Fluids.
Durban ...	Douglas W. Freshfield.........	The Mountains of the Old World.
	Prof. W. A. Herdman, F.R.S.	Marine Biology.
Pietermaritzburg.	Col. D. Bruce, C.B., F.R.S....	Sleeping Sickness.
	H. T. Ferrar	The Cruise of the 'Discovery.'
Johannesburg	Prof. W. E. Ayrton, F.R.S....	The Distribution of Power.
	Prof. J. O. Arnold..............	Steel as an Igneous Rock.
Pretoria ...	A. E. Shipley, F.R.S.	Fly-borne Diseases: Malaria, Sleeping Sickness, &c.
Bloemfontein...	A. R. Hinks	The Milky Way and the Clouds of Magellan.
Kimberley ...	Sir Wm. Crookes, F.R.S.......	Diamonds.
	Prof. J. B. Porter	The Bearing of Engineering on Mining.
Bulawayo ...	D. Randall-MacIver	The Ruins of Rhodesia.
1906. York.........	Dr. Tempest Anderson.........	Volcanoes.
	Dr. A. D. Waller, F.R.S.	The Electrical Signs of Life, and their Abolition by Chloroform.
1907. Leicester...	W. Duddell, F.R.S.	The Ark and the Spark in Radio-telegraphy.
	Dr. F. A. Dixey..................	Recent Developments in the Theory of Mimicry.
1908. Dublin......	Prof. H. H. Turner, F.R.S. ...	Halley's Comet.
	Prof. W. M Davis.	The Lessons of the Colorado Canyon.
1909. Winnipeg...	Dr. A. E. H. Tutton, F.R.S....	The Seven Styles of Crystal Architecture.
	Prof. W. A. Herdman, F.R.S.	Our Food from the Waters.
	[1] Prof. H. B. Dixon, F.R.S....	The Chemistry of Flame.
	[1] Prof. J. H. Poynting, F.R.S.	The Pressure of Light.
1910. Sheffield ...	Prof. W. Stirling, M.D.	Types of Animal Movement.[2]
	D. G. Hogarth	New Discoveries about the Hittites.

[1] 'Popular Lectures,' delivered to the citizens of Winnipeg.
[2] Repeated, to the public, on Wednesday, September 7.

LECTURES TO THE OPERATIVE CLASSES.

Date and Place	Lecturers	Subject of Lecture
1867. Dundee......	Prof. J. Tyndall, LL.D., F.R.S.	Matter and Force.
1868. Norwich ...	Prof. Huxley, LL.D., F.R.S.	A Piece of Chalk.
1869. Exeter	Prof. Miller, M.D., F.R.S. ...	The modes of detecting the Composition of the Sun and other Heavenly Bodies by the Spectrum.
1870. Liverpool...	Sir John Lubbock, Bart., F.R.S.	Savages.
1872. Brighton ...	W. Spottiswoode, LL.D., F.R.S.	Sunshine, Sea, and Sky.
1873. Bradford ...	C. W. Siemens, D.C.L., F.R.S.	Fuel.
1874. Belfast	Prof. Odling, F.R.S............	The Discovery of Oxygen.
1875. Bristol	Dr. W. B. Carpenter, F.R.S.	A Piece of Limestone.
1876. Glasgow ...	Commander Cameron, C.B....	A Journey through Africa.
1877. Plymouth...	W. H. Preece.....................	Telegraphy and the Telephone.
1879. Sheffield ...	W. E. Ayrton	Electricity as a Motive Power
1880. Swansea ...	H. Seebohm, F.Z.S.	The North-East Passage.
1881. York	Prof. Osborne Reynolds, F.R.S.	Raindrops, Hailstones, and Snowflakes.
1882. Southampton.	Dr. John Evans, Treas. R.S.	Unwritten History, and how to read it.
1883. Southport...	Sir F. J. Bramwell, F.R.S. ...	Talking by Electricity—Telephones.
1884. Montreal ...	Prof. R. S. Ball, F.R.S.	Comets.
1885. Aberdeen...	H. B. Dixon, M.A.	The Nature of Explosions.
1886. Birmingham	Prof. W. C. Roberts-Austen, F.R.S.	The Colours of Metals and their Alloys.
1887. Manchester	Prof. G. Forbes, F.R.S.	Electric Lighting.
1888. Bath	Sir John Lubbock, Bart., F.R.S.	The Customs of Savage Races.
1889. Newcastle-upon-Tyne	B. Baker, M.Inst.C.E.	The Forth Bridge.
1890. Leeds	Prof. J. Perry, D.Sc., F.R.S.	Spinning Tops.
1891. Cardiff	Prof. S. P. Thompson, F.R.S.	Electricity in Mining.
1892. Edinburgh..	Prof. C. Vernon Boys, F.R.S.	Electric Spark Photographs.
1893. Nottingham	Prof. Vivian B. Lewes	Spontaneous Combustion.
1894. Oxford	Prof. W. J. Sollas, F.R.S. ...	Geologies and Deluges.
1895. Ipswich ...	Dr. A. H. Fison...	Colour.
1896. Liverpool...	Prof. J. A. Fleming, F.R.S....	The Earth a Great Magnet.
1897. Toronto ...	Dr. H. O. Forbes	New Guinea.
1898. Bristol	Prof. E. B. Poulton, F.R.S. ...	The ways in which Animals Warn their Enemies and Signal to their Friends.
1900. Bradford...	Prof. S. P. Thompson, F.R.S.	Electricity in the Industries.
1901. Glasgow ...	H. J. Mackinder, M.A..........	The Movements of Men by Land and Sea.
1902. Belfast......	Prof. L. C. Miall, F.R.S.	Gnats and Mosquitoes.
1903. Southport...	Dr. J. S. Flett	Martinique and St. Vincent: the Eruptions of 1902.
1904. Cambridge..	Dr. J. E. Marr, F.R.S.	The Forms of Mountains.
1906. York.........	Prof. S. P. Thompson, F.R.S.	The Manufacture of Light.
1907. Leicester ...	Prof. H. A. Miers, F.R.S.......	The Growth of a Crystal.
1908. Dublin	Dr. A. E. H. Tutton, F.R.S.	The Crystallisation of Water.
1910. Sheffield ...	C. T. Heycock, F.R.S.	Metallic Alloys.

Table showing the Attendances and Receipts

Date of Meeting	Where held	Presidents	Old Life Members	New Life Members
1831, Sept. 27	York	Viscount Milton, D.C.L., F.R.S.	—	—
1832, June 19	Oxford	The Rev. W. Buckland, F.R.S.	—	—
1833, June 25	Cambridge	The Rev. A. Sedgwick, F.R.S.	—	—
1834, Sept. 8	Edinburgh	Sir T. M. Brisbane, D.C.L., F.R.S.	—	—
1835, Aug. 10	Dublin	The Rev. Provost Lloyd, LL.D., F.R.S.	—	—
1836, Aug. 22	Bristol	The Marquis of Lansdowne, F.R.S.	—	—
1837, Sept. 11	Liverpool	The Earl of Burlington, F.R.S.	—	—
1838, Aug. 10	Newcastle-on-Tyne	The Duke of Northumberland, F.R.S.	—	—
1839, Aug. 26	Birmingham	The Rev. W. Vernon Harcourt, F.R.S.	—	—
1840, Sept. 17	Glasgow	The Marquis of Breadalbane, F.R.S.	—	—
1841, July 20	Plymouth	The Rev. W. Whewell, F.R.S.	169	65
1842, June 23	Manchester	The Lord Francis Egerton, F.G.S.	303	169
1843, Aug. 17	Cork	The Earl of Rosse, F.R.S.	109	28
1844, Sept. 26	York	The Rev. G. Peacock, D.D., F.R.S.	226	150
1845, June 19	Cambridge	Sir John F. W. Herschel, Bart., F.R.S.	313	36
1846, Sept. 10	Southampton	Sir Roderick I. Murchison, Bart., F.R.S.	241	10
1847, June 23	Oxford	Sir Robert H. Inglis, Bart., F.R.S.	314	18
1848, Aug. 9	Swansea	The Marquis of Northampton, Pres.R.S.	149	3
1849, Sept. 12	Birmingham	The Rev. T. R. Robinson, D.D. F.R.S.	227	12
1850, July 21	Edinburgh	Sir David Brewster, K.H., F.R.S.	235	9
1851, July 2	Ipswich	G. B. Airy, Astronomer Royal, F.R.S.	172	8
1852, Sept. 1	Belfast	Lieut.-General Sabine, F.R.S.	164	10
1853, Sept. 3	Hull	William Hopkins, F.R.S.	141	13
1854, Sept. 20	Liverpool	The Earl of Harrowby, F.R.S.	238	23
1855, Sept. 12	Glasgow	The Duke of Argyll, F.R.S.	194	33
1856, Aug. 6	Cheltenham	Prof. C. G. B. Daubeny, M.D., F.R.S.	182	14
1857, Aug. 26	Dublin	The Rev. H. Lloyd, D.D., F.R.S.	236	15
1858, Sept. 22	Leeds	Richard Owen, M.D., D.C.L., F.R.S.	222	42
1859, Sept. 14	Aberdeen	H.R.H. The Prince Consort	184	27
1860, June 27	Oxford	The Lord Wrottesley, M.A., F.R.S.	286	21
1861, Sept. 4	Manchester	William Fairbairn, LL.D., F.R.S.	321	113
1862, Oct. 1	Cambridge	The Rev. Professor Willis, M.A., F.R.S.	239	15
1863, Aug. 26	Newcastle-on-Tyne	Sir William G. Armstrong, C.B., F.R.S.	203	36
1864, Sept. 13	Bath	Sir Charles Lyell, Bart., M.A., F.R.S.	287	40
1865, Sept. 6	Birmingham	Prof. J. Phillips, M.A., LL.D., F.R.S.	292	44
1866, Aug. 22	Nottingham	William R. Grove, Q.C., F.R.S.	207	31
1867, Sept. 4	Dundee	The Duke of Buccleuch, K.C.B., F.R.S.	167	25
1868, Aug. 19	Norwich	Dr. Joseph D. Hooker, F.R.S.	196	18
1869, Aug. 18	Exeter	Prof. G. G. Stokes, D.C.L., F.R.S.	204	21
1870, Sept. 14	Liverpool	Prof. T. H. Huxley, LL.D., F.R.S.	314	39
1871, Aug. 2	Edinburgh	Prof. Sir W. Thomson, LL.D., F.R.S.	246	28
1872, Aug. 14	Brighton	Dr. W. B. Carpenter, F.R.S.	245	36
1873, Sept. 17	Bradford	Prof. A. W. Williamson, F.R.S.	212	27
1874, Aug. 19	Belfast	Prof. J. Tyndall, LL.D., F.R.S.	162	13
1875, Aug. 25	Bristol	Sir John Hawkshaw, F.R.S.	239	36
1876, Sept. 6	Glasgow	Prof. T. Andrews, M.D., F.R.S.	221	35
1877, Aug. 15	Plymouth	Prof. A. Thomson, M.D., F.R.S.	173	19
1878, Aug. 14	Dublin	W. Spottiswoode, M.A., F.R.S.	201	18
1879, Aug. 20	Sheffield	Prof. G. J. Allman, M.D., F.R.S.	184	16
1880, Aug. 25	Swansea	A. C. Ramsay, LL.D., F.R.S.	144	11
1881, Aug. 31	York	Sir John Lubbock, Bart., F.R.S.	272	28
1882, Aug. 23	Southampton	Dr. C. W. Siemens, F.R.S.	178	17
1883, Sept. 19	Southport	Prof. A. Cayley, D.C.L., F.R.S.	203	60
1884, Aug. 27	Montreal	Prof. Lord Rayleigh, F.R.S.	235	20
1885, Sept. 9	Aberdeen	Sir Lyon Playfair, K.C.B., F.R.S.	225	18
1886, Sept. 1	Birmingham	Sir J. W. Dawson, C.M.G., F.R.S.	314	25
1887, Aug. 31	Manchester	Sir H. E. Roscoe, D.C.L., F.R.S.	428	86
1888, Sept. 5	Bath	Sir F. J. Bramwell, F.R.S.	266	36
1889, Sept. 11	Newcastle-on-Tyne	Prof. W. H. Flower, C.B., F.R.S.	277	20
1890, Sept. 3	Leeds	Sir F. A. Abel, C.B., F.R.S.	259	21
1891, Aug. 19	Cardiff	Dr. W. Huggins, F.R.S.	189	24
1892, Aug. 3	Edinburgh	Sir A. Geikie, LL.D., F.R.S.	280	14
1893, Sept. 13	Nottingham	Prof. J. S. Burdon Sanderson, F.R.S.	201	17
1894, Aug. 8	Oxford	The Marquis of Salisbury, K.G., F.R.S.	327	21
1895, Sept. 11	Ipswich	Sir Douglas Galton, K.C.B., F.R.S.	214	13
1896, Sept. 16	Liverpool	Sir Joseph Lister, Bart., Pres. R.S.	330	31
1897, Aug. 18	Toronto	Sir John Evans, K.C.B., F.R.S.	120	8
1898, Sept. 7	Bristol	Sir W. Crookes, F.R.S.	281	19
1899, Sept. 13	Dover	Sir Michael Foster, K.C.B., Sec.R.S.	296	20
1900, Sept. 5	Bradford	Sir William Turner, D.C.L., F.R.S.	267	13
1901, Sept. 11	Glasgow	Prof. A. W. Rücker, D.Sc., Sec.R.S.	310	37
1902, Sept. 10	Belfast	Prof. J. Dewar, LL.D., F.R.S.	243	21
1903, Sept. 9	Southport	Sir Norman Lockyer, K.C.B., F.R.S.	250	21
1904, Aug. 17	Cambridge	Rt. Hon. A. J. Balfour, M.P., F.R.S.	419	32
1905, Aug. 15	South Africa	Prof. G. H. Darwin, LL.D., F.R.S.	115	40
1906, Aug. 1	York	Prof. E. Ray Lankester, LL.D., F.R.S.	322	10
1907, July 31	Leicester	Sir David Gill, K.C.B., F.R.S.	276	19
1908, Sept. 2	Dublin	Dr. Francis Darwin, F.R.S.	294	24
1909, Aug. 25	Winnipeg	Prof. Sir J. J. Thomson, F.R.S.	117	13
1910, Aug. 31	Sheffield	Rev. Prof. T. G. Bonney, F.R.S.	293	26

* Ladies were not admitted by purchased tickets until 1843. † Tickets of Admission to Sections only.
¶ Including 848 Members of the South African Association.

at Annual Meetings of the Association.

Old Annual Members	New Annual Members	Associates	Ladies	Foreigners	Total	Amount received during the Meeting	Sums paid on account of Grants for Scientific Purposes	Year
—	—	—	—	—	353	—	—	1831
—	—	—	—	—	—	—	—	1832
—	—	—	—	—	900	—	—	1833
—	—	—	—	—	1298	—	£20 0 0	1834
—	—	—	—	—	—	—	167 0 0	1835
—	—	—	—	—	1350	—	435 0 0	1836
—	—	—	—	—	1840	—	922 12 6	1837
—	—	—	1100*	—	2400	—	932 2 2	1838
—	—	—	—	34	1438	—	1595 11 0	1839
—	—	—	—	40	1353	—	1546 16 4	1840
46	317	—	60*	—	891	—	1235 10 11	1841
75	376	33†	331*	28	1315	—	1449 17 8	1842
71	185	—	160	—	—	—	1565 10 2	1843
45	190	9†	260	—	—	—	981 12 8	1844
94	22	407	172	35	1079	—	831 9 9	1845
65	39	270	196	36	857	—	685 16 0	1846
197	40	495	203	53	1320	—	208 5 4	1847
54	25	376	197	15	819	£707 0 0	275 1 8	1848
93	33	447	237	22	1071	963 0 0	159 19 6	1849
128	42	510	273	44	1241	1085 0 0	345 18 0	1850
61	47	244	141	37	710	620 0 0	391 9 7	1851
63	60	510	292	9	1108	1085 0 0	304 6 7	1852
56	57	367	236	6	876	903 0 0	205 0 0	1853
121	121	765	524	10	1802	1882 0 0	380 19 7	1854
142	101	1094	543	26	2133	2311 0 0	480 16 4	1855
104	48	412	346	9	1115	1098 0 0	734 13 9	1856
156	120	900	569	26	2022	2015 0 0	507 15 4	1857
111	91	710	509	13	1698	1931 0 0	618 18 2	1858
125	179	1206	821	22	2564	2782 0 0	684 11 1	1859
177	59	636	463	47	1689	1604 0 0	766 19 6	1860
184	125	1589	791	15	3138	3944 0 0	1111 5 10	1861
150	57	433	242	25	1161	1089 0 0	1293 16 6	1862
154	209	1704	1004	25	3335	3640 0 0	1608 3 10	1863
182	103	1119	1058	13	2802	2965 0 0	1289 15 8	1864
215	149	766	508	23	1997	2227 0 0	1591 7 10	1865
218	105	960	771	11	2303	2469 0 0	1750 13 4	1866
193	118	1163	771	7	2444	2613 0 0	1739 4 0	1867
226	117	720	682	45‡	2004	2042 0 0	1940 0 0	1868
229	107	678	600	17	1856	1931 0 0	1622 0 0	1869
303	195	1103	910	14	2878	3096 0 0	1572 0 0	1870
311	127	976	754	21	2463	2575 0 0	1472 2 6	1871
280	80	937	912	43	2533	2649 0 0	1285 0 0	1872
237	99	796	601	11	1983	2120 0 0	1685 0 0	1873
232	85	817	630	12	1951	1979 0 0	1151 16 0	1874
307	93	884	672	17	2248	2397 0 0	960 0 0	1875
331	185	1265	712	25	2774	3023 0 0	1092 4 2	1876
238	59	446	283	11	1229	1268 0 0	1128 9 7	1877
290	93	1285	674	17	2578	2615 0 0	725 16 6	1878
239	74	529	349	13	1404	1425 0 0	1080 11 11	1879
171	41	389	147	12	915	899 0 0	731 7 7	1880
313	176	1230	514	24	2557	2689 0 0	476 8 1	1881
253	79	516	189	21	1253	1286 0 0	1126 1 11	1882
330	323	952	841	5	2714	3369 0 0	1083 3 3	1883
317	219	826	74	26 & 60 H.§	1777	1855 0 0	1173 4 0	1884
332	122	1053	447	6	2203	2256 0 0	1385 0 0	1885
428	179	1067	429	11	2453	2532 0 0	995 0 6	1886
510	244	1985	493	92	3838	4336 0 0	1186 18 0	1887
399	100	639	509	12	1984	2107 0 0	1511 0 5	1888
412	113	1024	579	21	2437	2441 0 0	1417 0 11	1889
368	92	680	334	12	1775	1776 0 0	789 16 8	1890
341	152	672	107	35	1497	1664 0 0	1029 10 0	1891
413	141	733	439	50	2070	2007 0 0	864 10 0	1892
328	57	773	268	17	1661	1653 0 0	907 15 6	1893
435	69	941	451	77	2321	2175 0 0	583 15 6	1894
290	31	493	261	22	1324	1236 0 0	977 15 5	1895
383	139	1384	873	41	3181	3228 0 0	1104 6 1	1896
286	125	682	100	41	1362	1398 0 0	1059 10 8	1897
327	96	1051	639	33	2446	2399 0 0	1212 0 0	1898
324	68	548	120	27	1403	1328 0 0	1430 14 2	1899
297	45	801	482	9	1915	1801 0 0	1072 10 0	1900
374	131	794	246	20	1912	2046 0 0	945 0 0	1901
314	86	647	305	6	1620	1644 0 0	947 0 0	1902
319	90	688	365	21	1754	1762 0 0	845 13 2	1903
449	113	1338	317	121	2789	2650 0 0	887 18 11	1904
937¶	411	430	181	16	2130	2422 0 0	928 2 2	1905
356	93	817	352	22	1972	1811 0 0	882 0 9	1906
339	61	659	251	42	1647	1561 0 0	757 12 10	1907
465	112	1166	222	14	2297	2317 0 0	1157 18 8	1908
290**	162	789	90	7	1468	1623 0 0	1014 9 9	1909
379	57	563	123	8	1449	1439 0 0	963 17 0	1910

‡ Including Ladies. § Fellows of the American Association were admitted as Hon. Members for this Meeting.
** Including 137 Members of the American Association.

ANALYSIS OF ATTENDANCES AT THE ANNUAL MEETINGS, 1831-1910.

[*The total attendances for the years* 1832, 1835, 1843, *and* 1844 *are unknown.*]

Average attendance at 76 *Meetings* : 1848.

	Average Attendance
Average attendance at 5 Meetings beginning during *June, between* 1833 *and* 1860	1260
Average attendance at 4 Meetings beginning during *July, between* 1841 *and* 1907	1122
Average attendance at 30 Meetings beginning during *August, between* 1836 *and* 1910	1943 [1]
Average attendance at 35 Meetings beginning during *September, between* 1831 *and* 1908	1944
Attendance at 1 Meeting held in *October, Cambridge,* 1862	1161

Meetings beginning during August and September.

Average attendance at—

4 Meetings beginning during the 1st week in *August* (1st- 7th)	1905
5 „ „ „ „ 2nd „ „ „ (8th-14th)	2130
8 „ „ „ „ 3rd „ „ „ (15th-21st)	1761 [2]
13 „ „ „ „ 4th „ „ „ (22nd-31st)	1996

Average attendance at—

12 Meetings beginning during the 1st week in *September* (1st- 7th)	2100
16 „ „ „ „ 2nd „ „ „ (8th-14th)	1860
5 „ „ „ „ 3rd „ „ „ (15th-21st)	2206
2 „ „ „ „ 4th „ „ „ (22nd-30th)	1025

Meetings beginning during June, July, and October.

Attendance at 1 Meeting (1845, June 19) beginning during the 3rd week in *June* (15th-21st)	1079
Average attendance at 4 Meetings beginning during the 4th week in *June* (22nd-30th)	1306
Attendance at 1 Meeting (1851, July 2) beginning during the 1st week in *July* (1st-7th)	710
Average attendance at 2 Meetings beginning during the 3rd week in *July* (15th-21st)	1066
Attendance at 1 Meeting (1907, July 31) beginning during the 5th week in *July* (29th-31st)	1647
Attendance at 1 Meeting (1862, October 1) beginning during the 1st week in *October* (1st-7th)	1161

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[1] Average attendance at 31 Meetings, *including* South Africa, 1905 (August 15-September 1): 1949.

[2] Average attendance at 9 Meetings, *including* South Africa, 1905 (August 15-September 1): 1802.

General Statement of Sums which have been paid on account of Grants for Scientific Purposes.

1834.

	£	s.	d.
Tide Discussions	20	0	0

1835.

	£	s.	d.
Tide Discussions	62	0	0
British Fossil Ichthyology	105	0	0
	£167	0	0

1836.

	£	s.	d.
Tide Discussions	163	0	0
British Fossil Ichthyology	105	0	0
Thermometric Observations, &c.	50	0	0
Experiments on Long-continued Heat	17	1	0
Rain-gauges	9	13	0
Refraction Experiments	15	0	0
Lunar Nutation	60	0	0
Thermometers	15	6	0
	£435	0	0

1837.

	£	s.	d.
Tide Discussions	284	1	0
Chemical Constants	24	13	6
Lunar Nutation	70	0	0
Observations on Waves	100	12	0
Tides at Bristol	150	0	0
Meteorology and Subterranean Temperature	93	3	0
Vitrification Experiments	150	0	0
Heart Experiments	8	4	6
Barometric Observations	30	0	0
Barometers	11	18	6
	£922	12	6

1838.

	£	s.	d.
Tide Discussions	29	0	0
British Fossil Fishes	100	0	0
Meteorological Observations and Anemometer Construction	100	0	0
Strength of Cast Iron	60	0	0
Preservation of Animal and Vegetable Substances	19	1	10
Railway Constants	41	12	10
Bristol Tides	50	0	0
Growth of Plants	75	0	0
Mud in Rivers	3	6	6
Education Committee	50	0	0
Heart Experiments	5	3	0
Land and Sea Level	267	8	7
Steam-vessels	100	0	0
Meteorological Committee	31	9	5
	£932	2	2

1839.

	£	s.	d.
Fossil Ichthyology	110	0	0
Meteorological Observations at Plymouth, &c.	63	10	0
Mechanism of Waves	144	2	0
Bristol Tides	35	18	6
Meteorology and Subterranean Temperature	21	11	0
Vitrification Experiments	9	4	0
Cast-iron Experiments	103	0	7
Railway Constants	28	7	0
Land and Sea Level	274	1	2
Steam-vessels' Engines	100	0	4
Stars in Histoire Céleste	171	18	0
Stars (Lacaille)	11	0	6
Stars in R.A.S. Catalogue	166	16	0
Animal Secretions	10	10	6
Steam Engines in Cornwall	50	0	0
Atmospheric Air	16	1	0
Cast and Wrought Iron	40	0	0
Heat on Organic Bodies	3	0	0
Gases on Solar Spectrum	22	0	0
Hourly Meteorological Observations, Inverness and Kingussie	49	7	8
Fossil Reptiles	118	2	9
Mining Statistics	50	0	0
	£1595	11	0

1840.

	£	s.	d.
Bristol Tides	100	0	0
Subterranean Temperature	13	13	6
Heart Experiments	18	19	0
Lungs Experiments	8	13	0
Tide Discussions	50	0	0
Land and Sea Level	6	11	1
Stars (Histoire Céleste)	242	10	0
Stars (Lacaille)	4	15	0
Stars (Catalogue)	264	0	0
Atmospheric Air	15	15	0
Water on Iron	10	0	0
Heat on Organic Bodies	7	0	0
Meteorological Observations	52	17	6
Foreign Scientific Memoirs	112	1	6
Working Population	100	0	0
School Statistics	50	0	0
Forms of Vessels	184	7	0
Chemical and Electrical Phenomena	40	0	0
Meteorological Observations at Plymouth	80	0	0
Magnetical Observations	185	13	9
	£1546	16	4

1841.

	£	s.	d.
Observations on Waves	30	0	0
Meteorology and Subterranean Temperature	8	8	0
Actinometers	10	0	0
Earthquake Shocks	17	7	0
Acrid Poisons	6	0	0
Veins and Absorbents	3	0	0
Mud in Rivers	5	0	0
Marine Zoology	15	12	8
Skeleton Maps	20	0	0
Mountain Barometers	6	18	6
Stars (Histoire Céleste)	185	0	0
Stars (Lacaille)	79	5	0
Stars (Nomenclature of)	17	19	6
Stars (Catalogue of)	40	0	0
Water on Iron	50	0	0
Meteorological Observations at Inverness	20	0	0
Meteorological Observations (reduction of)	25	0	0
Fossil Reptiles	50	0	0
Foreign Memoirs	62	0	6
Railway Sections	38	1	0
Forms of Vessels	193	12	0
Meteorological Observations at Plymouth	55	0	0
Magnetical Observations	61	18	8
Fishes of the Old Red Sandstone	100	0	0
Tides at Leith	50	0	0
Anemometer at Edinburgh	69	1	10
Tabulating Observations	9	6	3
Races of Men	5	0	0
Radiate Animals	2	0	0
	£1235	10	11

1842.

	£	s.	d.
Dynamometric Instruments	113	11	2
Anoplura Britanniæ	52	12	0
Tides at Bristol	59	8	0
Gases on Light	30	14	7
Chronometers	26	17	6
Marine Zoology	1	5	0
British Fossil Mammalia	100	0	0
Statistics of Education	20	0	0
Marine Steam-vessels' Engines	28	0	0
Stars (Histoire Céleste)	59	0	0
Stars (Brit. Assoc. Cat. of)	110	0	0
Railway Sections	161	10	0
British Belemnites	50	0	0
Fossil Reptiles (publication of Report)	210	0	0
Forms of Vessels	180	0	0
Galvanic Experiments on Rocks	5	8	6
Meteorological Experiments at Plymouth	68	0	0
Constant Indicator and Dynamometric Instruments	90	0	0
Force of Wind	10	0	0
Light on Growth of Seeds	8	0	0
Vital Statistics	50	0	0
Vegetative Power of Seeds	8	1	11
Questions on Human Race	7	9	0
	£1449	17	8

1843.

	£	s.	d.
Revision of the Nomenclature of Stars	2	0	0
Reduction of Stars, British Association Catalogue	25	0	0
Anomalous Tides, Firth of Forth	120	0	0
Hourly Meteorological Observations at Kingussie and Inverness	77	12	8
Meteorological Observations at Plymouth	55	0	0
Whewell's Meteorological Anemometer at Plymouth	10	0	0
Meteorological Observations, Osler's Anemometer at Plymouth	20	0	0
Reduction of Meteorological Observations	30	0	0
Meteorological Instruments and Gratuities	39	6	0
Construction of Anemometer at Inverness	56	12	2
Magnetic Co-operation	10	8	10
Meteorological Recorder for Kew Observatory	50	0	0
Action of Gases on Light	18	16	1
Establishment at Kew Observatory, Wages, Repairs, Furniture, and Sundries	133	4	7
Experiments by Captive Balloons	81	8	0
Oxidation of the Rails of Railways	20	0	0
Publication of Report on Fossil Reptiles	40	0	0
Coloured Drawings of Railway Sections	147	18	3
Registration of Earthquake Shocks	30	0	0
Report on Zoological Nomenclature	10	0	0
Uncovering Lower Red Sandstone near Manchester	4	4	6
Vegetative Power of Seeds	5	3	8
Marine Testacea (Habits of)	10	0	0
Marine Zoology	10	0	0
Marine Zoology	2	14	11
Preparation of Report on British Fossil Mammalia	100	0	0
Physiological Operations of Medicinal Agents	20	0	0
Vital Statistics	36	5	8

	£	s.	d.
Additional Experiments on the Forms of Vessels	70	0	0
Additional Experiments on the Forms of Vessels	100	0	0
Reduction of Experiments on the Forms of Vessels	100	0	0
Morin's Instrument and Constant Indicator	69	14	10
Experiments on the Strength of Materials	60	0	0
	£1565	10	2

1844.

	£	s.	d.
Meteorological Observations at Kingussie and Inverness	12	0	0
Completing Observations at Plymouth	35	0	0
Magnetic and Meteorological Co-operation	25	8	4
Publication of the British Association Catalogue of Stars	35	0	0
Observations on Tides on the East Coast of Scotland ...	100	0	0
Revision of the Nomenclature of Stars 1842	2	9	6
Maintaining the Establishment at Kew Observatory	117	17	3
Instruments for Kew Observatory	56	7	3
Influence of Light on Plants	10	0	0
Subterraneous Temperature in Ireland	5	0	0
Coloured Drawings of Railway Sections	15	17	6
Investigation of Fossil Fishes of the Lower Tertiary Strata	100	0	0
Registering the Shocks of Earthquakes 1842	23	11	10
Structure of Fossil Shells......	20	0	0
Radiata and Mollusca of the Ægean and Red Seas 1842	100	0	0
Geographical Distributions of Marine Zoology 1842	0	10	0
Marine Zoology of Devon and Cornwall	10	0	0
Marine Zoology of Corfu	10	0	0
Experiments on the Vitality of Seeds........	9	0	3
Experiments on the Vitality of Seeds 1842	8	7	3
Exotic Anoplura	15	0	0
Strength of Materials	100	0	0
Completing Experiments on the Forms of Ships	100	0	0
Inquiries into Asphyxia	10	0	0
Investigations on the Internal Constitution of Metals	50	0	0
Constant Indicator and Morin's Instrument.........1842	10	3	6
	£981	12	8

1845.

	£	s.	d.
Publication of the British Association Catalogue of Stars	351	14	6
Meteorological Observations at Inverness	30	18	11
Magnetic and Meteorological Co-operation	16	16	8
Meteorological Instruments at Edinburgh.................	18	11	9
Reduction of Anemometrical Observations at Plymouth	25	0	0
Electrical Experiments at Kew Observatory	43	17	8
Maintaining the Establishment at Kew Observatory	149	15	0
For Kreil's Barometrograph	25	0	0
Gases from Iron Furnaces ...	50	0	0
The Actinograph	15	0	0
Microscopic Structure of Shells	20	0	0
Exotic Anoplura 1843	10	0	0
Vitality of Seeds 1843	2	0	7
Vitality of Seeds 1844	7	0	0
Marine Zoology of Cornwall...	10	0	0
Physiological Action of Medicines............................	20	0	0
Statistics of Sickness and Mortality in York	20	0	0
Earthquake Shocks 1843	15	14	8
	£831	9	9

1846.

	£	s.	d.
British Association Catalogue of Stars 1844	211	15	0
Fossil Fishes of the London Clay	100	0	0
Computation of the Gaussian Constants for 1829	50	0	0
Maintaining the Establishment at Kew Observatory...	146	16	7
Strength of Materials	60	0	0
Researches in Asphyxia	6	16	2
Examination of Fossil Shells	10	0	0
Vitality of Seeds 1844	2	15	10
Vitality of Seeds 1845	7	12	3
Marine Zoology of Cornwall	10	0	0
Marine Zoology of Britain ...	10	0	0
Exotic Anoplura 1844	25	0	0
Expenses attending Anemometers	11	7	6
Anemometers' Repairs	2	3	6
Atmospheric Waves	3	3	3
Captive Balloons 1844	8	19	8
Varieties of the Human Race 1844	7	6	3
Statistics of Sickness and Mortality in York	12	0	0
	£685	16	0

1847.

	£	s.	d.
Computation of the Gaussian Constants for 1829	50	0	0
Habits of Marine Animals	10	0	0
Physiological Action of Medicines	20	0	0
Marine Zoology of Cornwall	10	0	0
Atmospheric Waves	6	9	3
Vitality of Seeds	4	7	7
Maintaining the Establishment at Kew Observatory	107	8	6
	£208	5	4

1848.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	171	15	11
Atmospheric Waves	3	10	9
Vitality of Seeds	9	15	0
Completion of Catalogue of Stars	70	0	0
On Colouring Matters	5	0	0
On Growth of Plants	15	0	0
	£275	1	8

1849.

	£	s.	d.
Electrical Observations at Kew Observatory	50	0	0
Maintaining the Establishment at ditto	76	2	5
Vitality of Seeds	5	8	1
On Growth of Plants	5	0	0
Registration of Periodical Phenomena	10	0	0
Bill on Account of Anemometrical Observations	13	9	0
	£159	19	6

1850.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	255	18	0
Transit of Earthquake Waves	50	0	0
Periodical Phenomena	15	0	0
Meteorological Instruments, Azores	25	0	0
	£345	18	0

1851.

	£	s.	d.
Maintaining the Establishment at Kew Observatory (including part of grant in 1849)	309	2	2
Theory of Heat	20	1	1
Periodical Phenomena of Animals and Plants	5	0	0
Vitality of Seeds	5	6	4
Influence of Solar Radiation	30	0	0
Ethnological Inquiries	12	0	0
Researches on Annelida	10	0	0
	£391	9	7

1852.

	£	s.	d.
Maintaining the Establishment at Kew Observatory (including balance of grant for 1850)	233	17	8
Experiments on the Conduction of Heat	5	2	9
Influence of Solar Radiations	20	0	0
Geological Map of Ireland	15	0	0
Researches on the British Annelida	10	0	0
Vitality of Seeds	10	6	2
Strength of Boiler Plates	10	0	0
	£304	6	7

1853.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	165	0	0
Experiments on the Influence of Solar Radiation	15	0	0
Researches on the British Annelida	10	0	0
Dredging on the East Coast of Scotland	10	0	0
Ethnological Queries	5	0	0
	£205	0	0

1854.

	£	s.	d.
Maintaining the Establishment at Kew Observatory (including balance of former grant)	330	15	4
Investigations on Flax	11	0	0
Effects of Temperature on Wrought Iron	10	0	0
Registration of Periodical Phenomena	10	0	0
British Annelida	10	0	0
Vitality of Seeds	5	2	3
Conduction of Heat	4	2	0
	£380	19	7

1855.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	425	0	0
Earthquake Movements	10	0	0
Physical Aspect of the Moon	11	8	5
Vitality of Seeds	10	7	11
Map of the World	15	0	0
Ethnological Queries	5	0	0
Dredging near Belfast	4	0	0
	£480	16	4

1856.

	£	s.	d.
Maintaining the Establishment at Kew Observatory:— 1854.........£ 75 0 0; 1855.........£500 0 0	575	0	0

	£	s.	d.
Strickland's Ornithological Synonyms	100	0	0
Dredging and Dredging Forms	9	13	9
Chemical Action of Light	20	0	0
Strength of Iron Plates	10	0	0
Registration of Periodical Phenomena	10	0	0
Propagation of Salmon	10	0	0
	£734	13	9

1857.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	350	0	0
Earthquake Wave Experiments	40	0	0
Dredging near Belfast	10	0	0
Dredging on the West Coast of Scotland	10	0	0
Investigations into the Mollusca of California	10	0	0
Experiments on Flax	5	0	0
Natural History of Madagascar	20	0	0
Researches on British Annelida	25	0	0
Report on Natural Products imported into Liverpool	10	0	0
Artificial Propagation of Salmon	10	0	0
Temperature of Mines	7	8	0
Thermometers for Subterranean Observations	5	7	4
Life-boats	5	0	0
	£507	15	4

1858.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	500	0	0
Earthquake Wave Experiments	25	0	0
Dredging on the West Coast of Scotland	10	0	0
Dredging near Dublin	5	0	0
Vitality of Seed	5	5	0
Dredging near Belfast	18	13	2
Report on the British Annelida	25	0	0
Experiments on the production of Heat by Motion in Fluids	20	0	0
Report on the Natural Products imported into Scotland	10	0	0
	£618	18	2

1859.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	500	0	0
Dredging near Dublin	15	0	0
Osteology of Birds	50	0	0
Irish Tunicata	5	0	0
Manure Experiments	20	0	0
British Medusidæ	5	0	0
Dredging Committee	5	0	0
Steam-vessels' Performance	5	0	0
Marine Fauna of South and West of Ireland	10	0	0
Photographic Chemistry	10	0	0
Lanarkshire Fossils	20	0	1
Balloon Ascents	39	11	0
	£684	11	1

1860.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	500	0	0
Dredging near Belfast	16	6	0
Dredging in Dublin Bay	15	0	0
Inquiry into the Performance of Steam-vessels	124	0	0
Explorations in the Yellow Sandstone of Dura Den	20	0	0
Chemico-mechanical Analysis of Rocks and Minerals	25	0	0
Researches on the Growth of Plants	10	0	0
Researches on the Solubility of Salts	30	0	0
Researches on the Constituents of Manures	25	0	0
Balance of Captive Balloon Accounts	1	13	6
	£766	19	6

1861.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	500	0	0
Earthquake Experiments	25	0	0
Dredging North and East Coasts of Scotland	23	0	0
Dredging Committee:— 1860......£50 0 0; 1861......£22 0 0	72	0	0
Excavations at Dura Den	20	0	0
Solubility of Salts	20	0	0
Steam-vessel Performance	150	0	0
Fossils of Lesmahagow	15	0	0
Explorations at Uriconium	20	0	0
Chemical Alloys	20	0	0
Classified Index to the Transactions	100	0	0
Dredging in the Mersey and Dee	5	0	0
Dip Circle	30	0	0
Photoheliographic Observations	50	0	0
Prison Diet	20	0	0
Gauging of Water	10	0	0
Alpine Ascents	6	5	10
Constituents of Manures	25	0	0
	£1111	5	10

1862.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	500	0	0
Patent Laws	21	6	0
Mollusca of N.-W. of America	10	0	0
Natural History by Mercantile Marine	5	0	0
Tidal Observations	25	0	0
Photoheliometer at Kew	40	0	0
Photographic Pictures of the Sun	150	0	0
Rocks of Donegal	25	0	0
Dredging Durham and Northumberland Coasts	25	0	0
Connection of Storms	20	0	0
Dredging North-east Coast of Scotland	6	9	6
Ravages of Teredo	3	11	0
Standards of Electrical Resistance	50	0	0
Railway Accidents	10	0	0
Balloon Committee	200	0	0
Dredging Dublin Bay	10	0	0
Dredging the Mersey	5	0	0
Prison Diet	20	0	0
Gauging of Water	12	10	0
Steamships' Performance	150	0	0
Thermo-electric Currents	5	0	0
	£1293	16	6

1863.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	600	0	0
Balloon Committee deficiency	70	0	0
Balloon Ascents (other expenses)	25	0	0
Entozoa	25	0	0
Coal Fossils	20	0	0
Herrings	20	0	0
Granites of Donegal	5	0	0
Prison Diet	20	0	0
Vertical Atmospheric Movements	13	0	0
Dredging Shetland	50	0	0
Dredging North-east Coast of Scotland	25	0	0
Dredging Northumberland and Durham	17	3	10
Dredging Committee Superintendence	10	0	0
Steamship Performance	100	0	0
Balloon Committee	200	0	0
Carbon under pressure	10	0	0
Volcanic Temperature	100	0	0
Bromide of Ammonium	8	0	0
Electrical Standards	100	0	0
Electrical Construction and Distribution	40	0	0
Luminous Meteors	17	0	0
Kew Additional Buildings for Photoheliograph	100	0	0
Thermo-electricity	15	0	0
Analysis of Rocks	8	0	0
Hydroida	10	0	0
	£1608	3	10

1864.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	600	0	0
Coal Fossils	20	0	0
Vertical Atmospheric Movements	20	0	0
Dredging, Shetland	75	0	0
Dredging, Northumberland	25	0	0
Balloon Committee	200	0	0
Carbon under pressure	10	0	0
Standards of Electric Resistance	100	0	0
Analysis of Rocks	10	0	0
Hydroida	10	0	0
Askham's Gift	50	0	0
Nitrite of Amyle	10	0	0
Nomenclature Committee	5	0	0
Rain-gauges	19	15	8
Cast-iron Investigation	20	0	0
Tidal Observations in the Humber	50	0	0
Spectral Rays	45	0	0
Luminous Meteors	20	0	0
	£1289	15	8

1865.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	600	0	0
Balloon Committee	100	0	0
Hydroida	13	0	0
Rain-gauges	30	0	0
Tidal Observations in the Humber	6	8	0
Hexylic Compounds	20	0	0
Amyl Compounds	20	0	0
Irish Flora	25	0	0
American Mollusca	3	9	0
Organic Acids	20	0	0
Lingula Flags Excavation	10	0	0
Eurypterus	50	0	0
Electrical Standards	100	0	0
Malta Caves Researches	30	0	0
Oyster Breeding	25	0	0
Gibraltar Caves Researches	150	0	0
Kent's Hole Excavations	100	0	0
Moon's Surface Observations	35	0	0
Marine Fauna	25	0	0
Dredging Aberdeenshire	25	0	0
Dredging Channel Islands	50	0	0
Zoological Nomenclature	5	0	0
Resistance of Floating Bodies in Water	100	0	0
Bath Waters Analysis	8	10	10
Luminous Meteors	40	0	0
	£1591	7	10

1866.

	£	s.	d.
Maintaining the Establishment at Kew Observatory..	600	0	0
Lunar Committee	64	13	4
Balloon Committee	50	0	0
Metrical Committee	50	0	0
British Rainfall	50	0	0
Kilkenny Coal Fields	16	0	0
Alum Bay Fossil Leaf-bed	15	0	0
Luminous Meteors	50	0	0
Lingula Flags Excavation	20	0	0
Chemical Constitution of Cast Iron	50	0	0
Amyl Compounds	25	0	0
Electrical Standards	100	0	0
Malta Caves Exploration	30	0	0
Kent's Hole Exploration	200	0	0
Marine Fauna, &c., Devon and Cornwall	25	0	0
DredgingAberdeenshireCoast	25	0	0
Dredging Hebrides Coast	50	0	0
Dredging the Mersey	5	0	0
Resistance of Floating Bodies in Water	50	0	0
Polycyanides of Organic Radicals	29	0	0
Rigor Mortis	10	0	0
Irish Annelida	15	0	0
Catalogue of Crania	50	0	0
Didine Birds of Mascarene Islands	50	0	0
Typical Crania Researches	30	0	0
Palestine Exploration Fund	100	0	0
	£1750	13	4

1867.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	600	0	0
Meteorological Instruments, Palestine	50	0	0
Lunar Committee	120	0	0
Metrical Committee	30	0	0
Kent's Hole Explorations	100	0	0
Palestine Explorations	50	0	0
Insect Fauna, Palestine	30	0	0
British Rainfall	50	0	0
Kilkenny Coal Fields	25	0	0
Alum Bay Fossil Leaf-bed	25	0	0
Luminous Meteors	50	0	0
Bournemouth, &c., Leaf-beds	30	0	0
Dredging Shetland	75	0	0
Steamship Reports Condensation	100	0	0
Electrical Standards	100	0	0
Ethyl and Methyl Series	25	0	0
Fossil Crustacea	25	0	0
Sound under Water	24	4	0
North Greenland Fauna	75	0	0
North Greenland Plant Beds	100	0	0
Iron and Steel Manufacture	25	0	0
Patent Laws	30	0	0
	£1739	4	0

1868.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	600	0	0
Lunar Committee	120	0	0
Metrical Committee	50	0	0
Zoological Record	100	0	0
Kent's Hole Explorations	150	0	0
Steamship Performances	100	0	0
British Rainfall	50	0	0
Luminous Meteors	50	0	0
Organic Acids	60	0	0
Fossil Crustacea	25	0	0
Methyl Series	25	0	0
Mercury and Bile	25	0	0
Organic Remains in Limestone Rocks	25	0	0
Scottish Earthquakes	20	0	0
Fauna, Devon and Cornwall	30	0	0
British Fossil Carols	50	0	0
Bagshot Leaf-beds	50	0	0
Greenland Explorations	100	0	0
Fossil Flora	25	0	0
Tidal Observations	100	0	0
Underground Temperature	50	0	0
Spectroscopic Investigations of Animal Substances	5	0	0
Secondary Reptiles, &c.	30	0	0
British Marine Invertebrate Fauna	100	0	0
	£1940	0	0

1869.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	600	0	0
Lunar Committee	50	0	0
Metrical Committee	25	0	0
Zoological Record	100	0	0
Committee on Gases in Deep-well Water	25	0	0
British Rainfall	50	0	0
Thermal Conductivity of Iron, &c.	30	0	0
Kent's Hole Explorations	150	0	0
Steamship Performances	30	0	0
Chemical Constitution of Cast Iron	80	0	0
Iron and Steel Manufacture	100	0	0
Methyl Series	30	0	0
Organic Remains in Limestone Rocks	10	0	0
Earthquakes in Scotland	10	0	0
British Fossil Corals	50	0	0
Bagshot Leaf-beds	30	0	0
Fossil Flora	25	0	0
Tidal Observations	100	0	0
Underground Temperature	30	0	0
Spectroscopic Investigations of Animal Substances	5	0	0
Organic Acids	12	0	0
Kiltorcan Fossils	20	0	0

	£	s.	d.
Chemical Constitution and Physiological Action Relations	15	0	0
Mountain Limestone Fossils	25	0	0
Utilisation of Sewage	10	0	0
Products of Digestion	10	0	0
	£1622	0	0

1870.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	600	0	0
Metrical Committee	25	0	0
Zoological Record	100	0	0
Committee on Marine Fauna	20	0	0
Ears in Fishes	10	0	0
Chemical Nature of Cast Iron	80	0	0
Luminous Meteors	30	0	0
Heat in the Blood	15	0	0
British Rainfall	100	0	0
Thermal Conductivity of Iron, &c.	20	0	0
British Fossil Corals	50	0	0
Kent's Hole Explorations	150	0	0
Scottish Earthquakes	4	0	0
Bagshot Leaf-beds	15	0	0
Fossil Flora	25	0	0
Tidal Observations	100	0	0
Underground Temperature	50	0	0
Kiltorcan Quarries Fossils	20	0	0
Mountain Limestone Fossils	25	0	0
Utilisation of Sewage	50	0	0
Organic Chemical Compounds	30	0	0
Onny River Sediment	3	0	0
Mechanical Equivalent of Heat	50	0	0
	£1572	0	0

1871.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	600	0	0
Monthly Reports of Progress in Chemistry	100	0	0
Metrical Committee	25	0	0
Zoological Record	100	0	0
Thermal Equivalents of the Oxides of Chlorine	10	0	0
Tidal Observation	100	0	0
Fossil Flora	25	0	0
Luminous Meteors	30	0	0
British Fossil Corals	25	0	0
Heat in the Blood	7	2	6
British Rainfall	50	0	0
Kent's Hole Explorations	150	0	0
Fossil Crustacea	25	0	0
Methyl Compounds	25	0	0
Lunar Objects	20	0	0
Fossil Coral Sections, for Photographing	20	0	0
Bagshot Leaf-beds	20	0	0
Moab Explorations	100	0	0
Gaussian Constants	40	0	0
	£1472	2	6

1872.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	300	0	0
Metrical Committee	75	0	0
Zoological Record	100	0	0
Tidal Committee	200	0	0
Carboniferous Corals	25	0	0
Organic Chemical Compounds	25	0	0
Exploration of Moab	100	0	0
Terato-embryological Inquiries	10	0	0
Kent's Cavern Exploration	100	0	0
Luminous Meteors	20	0	0
Heat in the Blood	15	0	0
Fossil Crustacea	25	0	0
Fossil Elephants of Malta	25	0	0
Lunar Objects	20	0	0
Inverse Wave-lengths	20	0	0
British Rainfall	100	0	0
Poisonous Substances Antagonism	10	0	0
Essential Oils, Chemical Constitution, &c.	40	0	0
Mathematical Tables	50	0	0
Thermal Conductivity of Metals	25	0	0
	£1285	0	0

1873.

	£	s.	d.
Zoological Record	100	0	0
Chemistry Record	200	0	0
Tidal Committee	400	0	0
Sewage Committee	100	0	0
Kent's Cavern Exploration	150	0	0
Carboniferous Corals	25	0	0
Fossil Elephants	25	0	0
Wave-lengths	150	0	0
British Rainfall	100	0	0
Essential Oils	30	0	0
Mathematical Tables	100	0	0
Gaussian Constants	10	0	0
Sub-Wealden Explorations	25	0	0
Underground Temperature	150	0	0
Settle Cave Exploration	50	0	0
Fossil Flora, Ireland	20	0	0
Timber Denudation and Rainfall	20	0	0
Luminous Meteors	30	0	0
	£1685	0	0

1874.

	£	s.	d.
Zoological Record	100	0	0
Chemistry Record	100	0	0
Mathematical Tables	100	0	0
Elliptic Functions	100	0	0
Lightning Conductors	10	0	0
Thermal Conductivity of Rocks	10	0	0
Anthropological Instructions	50	0	0
Kent's Cavern Exploration	150	0	0
Luminous Meteors	30	0	0
Intestinal Secretions	15	0	0
British Rainfall	100	0	0
Essential Oils	10	0	0
Sub-Wealden Explorations	25	0	0
Settle Cave Exploration	50	0	0
Mauritius Meteorology	100	0	0
Magnetisation of Iron	20	0	0
Marine Organisms	30	0	0
Fossils, North-West of Scotland	2	10	0
Physiological Action of Light	20	0	0
Trades Unions	25	0	0
Mountain Limestone Corals	25	0	0
Erratic Blocks	10	0	0
Dredging, Durham and Yorkshire Coasts	28	5	0
High Temperature of Bodies	30	0	0
Siemens's Pyrometer	3	6	0
Labyrinthodonts of Coal-measures	7	15	0
	£1151	16	0

1875.

	£	s.	d.
Elliptic Functions	100	0	0
Magnetisation of Iron	20	0	0
British Rainfall	120	0	0
Luminous Meteors	30	0	0
Chemistry Record	100	0	0
Specific Volume of Liquids	25	0	0
Estimation of Potash and Phosphoric Acid	10	0	0
Isometric Cresols	20	0	0
Sub-Wealden Explorations	100	0	0
Kent's Cavern Exploration	100	0	0
Settle Cave Exploration	50	0	0
Earthquakes in Scotland	15	0	0
Underground Waters	10	0	0
Development of Myxinoid Fishes	20	0	0
Zoological Record	100	0	0
Instructions for Travellers	20	0	0
Intestinal Secretions	20	0	0
Palestine Exploration	100	0	0
	£960	0	0

1876.

	£	s.	d.
Printing Mathematical Tables	159	4	2
British Rainfall	100	0	0
Ohm's Law	9	15	0
Tide Calculating Machine	200	0	0
Specific Volume of Liquids	25	0	0
Isomeric Cresols	10	0	0
Action of Ethyl Bromobutyrate on Ethyl Sodaceto-acetate	5	0	0
Estimation of Potash and Phosphoric Acid	13	0	0
Exploration of Victoria Cave	100	0	0
Geological Record	100	0	0
Kent's Cavern Exploration	100	0	0
Thermal Conductivities of Rocks	10	0	0
Underground Waters	10	0	0
Earthquakes in Scotland	1	10	0
Zoological Record	100	0	0
Close Time	5	0	0
Physiological Action of Sound	25	0	0
Naples Zoological Station	75	0	0
Intestinal Secretions	15	0	0
Physical Characters of Inhabitants of British Isles	13	15	0
Measuring Speed of Ships	10	0	0
Effect of Propeller on turning of Steam-vessels	5	0	0
	£1092	4	2

1877.

	£	s.	d.
Liquid Carbonic Acid in Minerals	20	0	0
Elliptic Functions	250	0	0
Thermal Conductivity of Rocks	9	11	7
Zoological Record	100	0	0
Kent's Cavern	100	0	0
Zoological Station at Naples	75	0	0
Luminous Meteors	30	0	0
Elasticity of Wires	100	0	0
Dipterocarpeæ, Report on	20	0	0
Mechanical Equivalent of Heat	35	0	0
Double Compounds of Cobalt and Nickel	8	0	0
Underground Temperature	50	0	0
Settle Cave Exploration	100	0	0
Underground Waters in New Red Sandstone	10	0	0
Action of Ethyl Bromobutyrate on Ethyl Sodaceto-acetate	10	0	0
British Earthworks	25	0	0
Atmospheric Electricity in India	15	0	0
Development of Light from Coal-gas	20	0	0
Estimation of Potash and Phosphoric Acid	1	18	0
Geological Record	100	0	0
Anthropometric Committee	34	0	0
Physiological Action of Phosphoric Acid, &c.	15	0	0
	£1128	9	7

1878.

	£	s.	d.
Exploration of Settle Caves...	100	0	0
Geological Record...............	100	0	0
Investigation of Pulse Phenomena by means of Siphon Recorder........................	10	0	0
Zoological Station at Naples	75	0	0
Investigation of Underground Waters..........................	15	0	0
Transmission of Electrical Impulses through Nerve Structure........................	30	0	0
Calculation of Factor Table for Fourth Million	100	0	0
Anthropometric Committee...	66	0	0
Composition and Structure of less-known Alkaloids	25	0	0
Exploration of Kent's Cavern	50	0	0
Zoological Record...............	100	0	0
Fermanagh Caves Exploration	15	0	0
Thermal Conductivity of Rocks	4	16	6
Luminous Meteors..............	10	0	0
Ancient Earthworks	25	0	0
	£725	16	6

1879.

	£	s.	d.
Table at the Zoological Station, Naples	75	0	0
Miocene Flora of the Basalt of the North of Ireland ...	20	0	0
Illustrations for a Monograph on the Mammoth	17	0	0
Record of Zoological Literature	100	0	0
Composition and Structure of less-known Alkaloids	25	0	0
Exploration of Caves in Borneo	50	0	0
Kent's Cavern Exploration ...	100	0	0
Record of the Progress of Geology	100	0	0
Fermanagh Caves Exploration	5	0	0
Electrolysis of Metallic Solutions and Solutions of Compound Salts..............	25	0	0
Anthropometric Committee...	50	0	0
Natural History of Socotra ...	100	0	0
Calculation of Factor Tables for 5th and 6th Millions ...	150	0	0
Underground Waters...........	10	0	0
Steering of Screw Steamers...	10	0	0
Improvements in Astronomical Clocks	30	0	0
Marine Zoology of South Devon	20	0	0
Determination of Mechanical Equivalent of Heat	12	15	6
Specific Inductive Capacity of Sprengel Vacuum.........	40	0	0
Tables of Sun-heat Coefficients	30	0	0
Datum Level of the Ordnance Survey	10	0	0
Tables of Fundamental Invariants of Algebraic Forms	36	14	9
Atmospheric Electricity Observations in Madeira	15	0	0
Instrument for Detecting Fire-damp in Mines	22	0	0
Instruments for Measuring the Speed of Ships	17	1	8
Tidal Observations in the English Channel	10	0	0
	£1080	11	11

1880.

	£	s.	d.
New Form of High Insulation Key	10	0	0
Underground Temperature ...	10	0	0
Determination of the Mechanical Equivalent of Heat	8	5	0
Elasticity of Wires	50	0	0
Luminous Meteors	30	0	0
Lunar Disturbance of Gravity	30	0	0
Fundamental Invariants	8	5	0
Laws of Water Friction	20	0	0
Specific Inductive Capacity of Sprengel Vacuum.........	20	0	0
Completion of Tables of Sun-heat Coefficients	50	0	0
Instrument for Detection of Fire-damp in Mines	10	0	0
Inductive Capacity of Crystals and Paraffines	4	17	7
Report on Carboniferous Polyzoa	10	0	0
Caves of South Ireland	10	0	0
Viviparous Nature of Ichthyosaurus	10	0	0
Kent's Cavern Exploration ...	50	0	0
Geological Record..............	100	0	0
Miocene Flora of the Basalt of North Ireland	15	0	0
Underground Waters of Permian Formations	5	0	0
Record of Zoological Literature	100	0	0
Table at Zoological Station at Naples	75	0	0
Investigation of the Geology and Zoology of Mexico......	50	0	0
Anthropometry	50	0	0
Patent Laws	5	0	0
	£731	7	7

1881.

	£	s.	d.
Lunar Disturbance of Gravity	30	0	0
Underground Temperature ...	20	0	0
Electrical Standards...........	25	0	0
High Insulation Key...........	5	0	0
Tidal Observations	10	0	0
Specific Refractions	7	3	1
Fossil Polyzoa	10	0	0
Underground Waters	10	0	0
Earthquakes in Japan	25	0	0
Tertiary Flora	20	0	0
Scottish Zoological Station ...	50	0	0
Naples Zoological Station ...	75	0	0
Natural History of Socotra ...	50	0	0
Anthropological Notes and Queries	9	0	0
Zoological Record..............	100	0	0
Weights and Heights of Human Beings	30	0	0
	£476	3	1

1882.

	£	s.	d.
Exploration of Central Africa	100	0	0
Fundamental Invariants of Algebraical Forms	76	1	11
Standards for Electrical Measurements	100	0	0
Calibration of Mercurial Thermometers	20	0	0
Wave-length Tables of Spectra of Elements...............	50	0	0
Photographing Ultra-violet Spark Spectra	25	0	0
Geological Record..............	100	0	0
Earthquake Phenomena of Japan	25	0	0
Conversion of Sedimentary Materials into Metamorphic Rocks	10	0	0
Fossil Plants of Halifax	15	0	0
Geological Map of Europe ...	25	0	0
Circulation of Underground Waters.........................	15	0	0
Tertiary Flora of North of Ireland	20	0	0
British Polyzoa	10	0	0
Exploration of Caves of South of Ireland	10	0	0
Exploration of Raygill Fissure	20	0	0
Naples Zoological Station ...	80	0	0
Albuminoid Substances of Serum	10	0	0
Elimination of Nitrogen by Bodily Exercise..............	50	0	0
Migration of Birds	15	0	0
Natural History of Socotra...	100	0	0
Natural History of Timor-laut	100	0	0
Record of Zoological Literature	100	0	0
Anthropometric Committee...	50	0	0
	£1126	1	11

1883.

	£	s.	d.
Meteorological Observations on Ben Nevis	50	0	0
Isomeric Naphthalene Derivatives............................	15	0	0
Earthquake Phenomena of Japan	50	0	0
Fossil Plants of Halifax	20	0	0
British Fossil Polyzoa	10	0	0
Fossil Phyllopoda of Palæozoic Rocks	25	0	0
Erosion of Sea-coast of England and Wales	10	0	0
Circulation of Underground Waters.........................	15	0	0
Geological Record..............	50	0	0
Exploration of Caves in South of Ireland	10	0	0
Zoological Literature Record	100	0	0
Migration of Birds	20	0	0
Zoological Station at Naples	80	0	0
Scottish Zoological Station...	25	0	0
Elimination of Nitrogen by Bodily Exercise..............	38	3	3
Exploration of Mount Kilima-njaro........................	500	0	0
Investigation of Loughton Camp	10	0	0
Natural History of Timor-laut	50	0	0
Screw Gauges....................	5	0	0
	£1083	3	3

1884.

	£	s.	d.
Meteorological Observations on Ben Nevis	50	0	0
Collecting and Investigating Meteoric Dust.................	20	0	0
Meteorological Observatory at Chepstow......................	25	0	0
Tidal Observations..............	10	0	0
Ultra Violet Spark Spectra ...	8	4	0
Earthquake Phenomena of Japan	75	0	0
Fossil Plants of Halifax	15	0	0
Fossil Polyzoa.....................	10	0	0
Erratic Blocks of England ...	10	0	0
Fossil Phyllopoda of Palæozoic Rocks	15	0	0
Circulation of Underground Waters.........................	5	0	0
International Geological Map	20	0	0
Bibliography of Groups of Invertebrata	50	0	0
Natural History of Timor-laut	50	0	0
Naples Zoological Station ...	80	0	0
Exploration of Mount Kilima-njaro, East Africa	500	0	0
Migration of Birds..............	20	0	0
Coagulation of Blood...........	100	0	0
Zoological Literature Record	100	0	0
Anthropometric Committee...	10	0	0
	£1173	4	0

1885.

	£	s.	d.
Synoptic Chart of Indian Ocean	50	0	0
Reduction of Tidal Observations	10	0	0
Calculating Tables in Theory of Numbers	100	0	0
Meteorological Observations on Ben Nevis	50	0	0
Meteoric Dust	70	0	0
Vapour Pressures, &c., of Salt Solutions	25	0	0
Physical Constants of Solutions	20	0	0
Volcanic Phenomena of Vesuvius	25	0	0
Raygill Fissure	15	0	0
Earthquake Phenomena of Japan	70	0	0
Fossil Phyllopoda of Palæozoic Rocks	25	0	0
Fossil Plants of British Tertiary and Secondary Beds	50	0	0
Geological Record	50	0	0
Circulation of Underground Waters	10	0	0
Naples Zoological Station	100	0	0
Zoological Literature Record	100	0	0
Migration of Birds	30	0	0
Exploration of Mount Kilimanjaro	25	0	0
Recent Polyzoa	10	0	0
Granton Biological Station	100	0	0
Biological Stations on Coasts of United Kingdom	150	0	0
Exploration of New Guinea	200	0	0
Exploration of Mount Roraima	100	0	0
	£1385	0	0

1886.

	£	s.	d.
Electrical Standards	40	0	0
Solar Radiation	9	10	6
Tidal Observations	50	0	0
Magnetic Observations	10	10	0
Observations on Ben Nevis	100	0	0
Physical and Chemical Bearings of Electrolysis	20	0	0
Chemical Nomenclature	5	0	0
Fossil Plants of British Tertiary and Secondary Beds	20	0	0
Caves in North Wales	25	0	0
Volcanic Phenomena of Vesuvius	30	0	0
Geological Record	100	0	0
Palæozoic Phyllopoda	15	0	0
Zoological Literature Record	100	0	0
Granton Biological Station	75	0	0
Naples Zoological Station	50	0	0
Researches in Food-Fishes and Invertebrata at St. Andrews	75	0	0
Migration of Birds	30	0	0
Secretion of Urine	10	0	0
Exploration of New Guinea	150	0	0
Regulation of Wages under Sliding Scales	10	0	0
Prehistoric Race in Greek Islands	20	0	0
North-Western Tribes of Canada	50	0	0
	£995	0	6

1887.

	£	s.	d.
Solar Radiation	18	10	0
Electrolysis	30	0	0
Ben Nevis Observatory	75	0	0
Standards of Light (1886 grant)	20	0	0
Standards of Light (1887 grant)	10	0	0
Harmonic Analysis of Tidal Observations	15	0	0
Magnetic Observations	26	2	0
Electrical Standards	50	0	0
Silent Discharge of Electricity	20	0	0
Absorption Spectra	40	0	0
Nature of Solution	20	0	0
Influence of Silicon on Steel	30	0	0
Volcanic Phenomena of Vesuvius	20	0	0
Volcanic Phenomena of Japan (1886 grant)	50	0	0
Volcanic Phenomena of Japan (1887 grant)	50	0	0
Cae Gwyn Cave, N. Wales	20	0	0
Erratic Blocks	10	0	0
Fossil Phyllopoda	20	0	0
Coal Plants of Halifax	25	0	0
Microscopic Structure of the Rocks of Anglesey	10	0	0
Exploration of the Eocene Beds of the Isle of Wight	20	0	0
Underground Waters	5	0	0
'Manure' Gravels of Wexford	10	0	0
Provincial Museums Reports	5	0	0
Lymphatic System	25	0	0
Naples Biological Station	100	0	0
Plymouth Biological Station	50	0	0
Granton Biological Station	75	0	0
Zoological Record	100	0	0
Flora of China	75	0	0
Flora and Fauna of the Cameroons	75	0	0
Migration of Birds	30	0	0
Bathy-hypsographical Map of British Isles	7	6	0
Regulation of Wages	10	0	0
Prehistoric Race of Greek Islands	20	0	0
Racial Photographs, Egyptian	20	0	0
	£1186	18	0

1888.

	£	s.	d.
Ben Nevis Observatory	150	0	0
Electrical Standards	2	6	4
Magnetic Observations	15	0	0
Standards of Light	79	2	3
Electrolysis	30	0	0
Uniform Nomenclature in Mechanics	10	0	0
Silent Discharge of Electricity	9	11	10
Properties of Solutions	25	0	0
Influence of Silicon on Steel	20	0	0
Methods of teaching Chemistry	10	0	0
Isomeric Naphthalene Derivatives	25	0	0
Action of Light on Hydracid	20	0	0
Sea Beach near Bridlington	20	0	0
Geological Record	50	0	0
Manure Gravels of Wexford	10	0	0
Erosion of Sea Coasts	10	0	0
Underground Waters	5	0	0
Palæontographical Society	50	0	0
Pliocene Fauna of St. Erth	50	0	0
Carboniferous Flora of Lancashire and West Yorkshire	25	0	0
Volcanic Phenomena of Vesuvius	20	0	0
Zoology and Botany of West Indies	100	0	0
Flora of Bahamas	100	0	0
Development of Fishes—St. Andrews	50	0	0
Marine Laboratory, Plymouth	100	0	0
Migration of Birds	30	0	0
Flora of China	75	0	0
Naples Zoological Station	100	0	0
Lymphatic System	25	0	0
Biological Station at Granton	50	0	0
Peradeniya Botanical Station	50	0	0
Development of Teleostei	15	0	0
Depth of Frozen Soil in Polar Regions	5	0	0
Precious Metals in Circulation	20	0	0
Value of Monetary Standard	10	0	0
Effect of Occupations on Physical Development	25	0	0
North-Western Tribes of Canada	100	0	0
Prehistoric Race in Greek Islands	20	0	0
	£1511	0	5

1889.

	£	s.	d.
Ben Nevis Observatory	50	0	0
Electrical Standards	75	0	0
Electrolysis	20	0	0
Surface Water Temperature	30	0	0
Silent Discharge of Electricity on Oxygen	6	4	8
Methods of teaching Chemistry	10	0	0
Action of Light on Hydracids	10	0	0
Geological Record	80	0	0
Volcanic Phenomena of Japan	25	0	0
Volcanic Phenomena of Vesuvius	20	0	0
Palæozoic Phyllopoda	20	0	0
Higher Eocene Beds of Isle of Wight	15	0	0
West Indian Explorations	100	0	0
Flora of China	25	0	0
Naples Zoological Station	100	0	0
Physiology of Lymphatic System	25	0	0
Experiments with a Tow-net	5	16	3
Natural History of Friendly Islands	100	0	0
Geology and Geography of Atlas Range	100	0	0
Action of Waves and Currents in Estuaries	100	0	0
North-Western Tribes of Canada	150	0	0
Nomad Tribes of Asia Minor	30	0	0
Corresponding Societies	20	0	0
Marine Biological Association	200	0	0
'Baths Committee,' Bath	100	0	0
	£1417	0	11

1890.

	£	s.	d.
Electrical Standards	12	17	0
Electrolysis	5	0	0
Electro-optics	50	0	0
Mathematical Tables	25	0	0
Volcanic and Seismological Phenomena of Japan	75	0	0
Pellian Equation Tables	15	0	0
Properties of Solutions	10	0	0
International Standard for the Analysis of Iron and Steel	10	0	0
Influence of the Silent Discharge of Electricity on Oxygen	5	0	0
Methods of teaching Chemistry	10	0	0
Recording Results of Water Analysis	4	1	0
Oxidation of Hydracids in Sunlight	15	0	0
Volcanic Phenomena of Vesuvius	20	0	0
Palæozoic Phyllopoda	10	0	0
Circulation of Underground Waters	5	0	0
Excavations at Oldbury Hill	15	0	0
Cretaceous Polyzoa	10	0	0
Geological Photographs	7	14	11
Lias Beds of Northampton	25	0	0
Botanical Station at Peradeniya	25	0	0

1885.

	£	s.	d.
Synoptic Chart of Indian Ocean	50	0	0
Reduction of Tidal Observations	10	0	0
Calculating Tables in Theory of Numbers	100	0	0
Meteorological Observations on Ben Nevis	50	0	0
Meteoric Dust	70	0	0
Vapour Pressures, &c., of Salt Solutions	25	0	0
Physical Constants of Solutions	20	0	0
Volcanic Phenomena of Vesuvius	25	0	0
Raygill Fissure	15	0	0
Earthquake Phenomena of Japan	70	0	0
Fossil Phyllopoda of Palæozoic Rocks	25	0	0
Fossil Plants of British Tertiary and Secondary Beds	50	0	0
Geological Record	50	0	0
Circulation of Underground Waters	10	0	0
Naples Zoological Station	100	0	0
Zoological Literature Record	100	0	0
Migration of Birds	30	0	0
Exploration of Mount Kilimanjaro	25	0	0
Recent Polyzoa	10	0	0
Granton Biological Station	100	0	0
Biological Stations on Coasts of United Kingdom	150	0	0
Exploration of New Guinea	200	0	0
Exploration of Mount Roraima	100	0	0
	£1385	0	0

1886.

	£	s.	d.
Electrical Standards	40	0	0
Solar Radiation	9	10	6
Tidal Observations	50	0	0
Magnetic Observations	10	10	0
Observations on Ben Nevis	100	0	0
Physical and Chemical Bearings of Electrolysis	20	0	0
Chemical Nomenclature	5	0	0
Fossil Plants of British Tertiary and Secondary Beds	20	0	0
Caves in North Wales	25	0	0
Volcanic Phenomena of Vesuvius	30	0	0
Geological Record	100	0	0
Palæozoic Phyllopoda	15	0	0
Zoological Literature Record	100	0	0
Granton Biological Station	75	0	0
Naples Zoological Station	50	0	0
Researches in Food-Fishes and Invertebrata at St. Andrews	75	0	0
Migration of Birds	30	0	0
Secretion of Urine	10	0	0
Exploration of New Guinea	150	0	0
Regulation of Wages under Sliding Scales	10	0	0
Prehistoric Race in Greek Islands	20	0	0
North-Western Tribes of Canada	50	0	0
	£995	0	6

1887.

	£	s.	d.
Solar Radiation	18	10	0
Electrolysis	30	0	0
Ben Nevis Observatory	75	0	0
Standards of Light (1886 grant)	20	0	0
Standards of Light (1887 grant)	10	0	0
Harmonic Analysis of Tidal Observations	15	0	0
Magnetic Observations	26	2	0
Electrical Standards	50	0	0
Silent Discharge of Electricity	20	0	0
Absorption Spectra	40	0	0
Nature of Solution	20	0	0
Influence of Silicon on Steel	30	0	0
Volcanic Phenomena of Vesuvius	20	0	0
Volcanic Phenomena of Japan (1886 grant)	50	0	0
Volcanic Phenomena of Japan (1887 grant)	50	0	0
Cae Gwyn Cave, N. Wales	20	0	0
Erratic Blocks	10	0	0
Fossil Phyllopoda	20	0	0
Coal Plants of Halifax	25	0	0
Microscopic Structure of the Rocks of Anglesey	10	0	0
Exploration of the Eocene Beds of the Isle of Wight	20	0	0
Underground Waters	5	0	0
'Manure' Gravels of Wexford	10	0	0
Provincial Museums Reports	5	0	0
Lymphatic System	25	0	0
Naples Biological Station	100	0	0
Plymouth Biological Station	50	0	0
Granton Biological Station	75	0	0
Zoological Record	100	0	0
Flora of China	75	0	0
Flora and Fauna of the Cameroons	75	0	0
Migration of Birds	30	0	0
Bathy-hypsographical Map of British Isles	7	6	0
Regulation of Wages	10	0	0
Prehistoric Race of Greek Islands	20	0	0
Racial Photographs, Egyptian	20	0	0
	£1186	18	0

1888.

	£	s.	d.
Ben Nevis Observatory	150	0	0
Electrical Standards	2	6	4
Magnetic Observations	15	0	0
Standards of Light	79	2	3
Electrolysis	30	0	0
Uniform Nomenclature in Mechanics	10	0	0
Silent Discharge of Electricity	9	11	10
Properties of Solutions	25	0	0
Influence of Silicon on Steel	20	0	0
Methods of teaching Chemistry	10	0	0
Isomeric Naphthalene Derivatives	25	0	0
Action of Light on Hydracid	20	0	0
Sea Beach near Bridlington	20	0	0
Geological Record	50	0	0
Manure Gravels of Wexford	10	0	0
Erosion of Sea Coasts	10	0	0
Underground Waters	5	0	0
Palæontographical Society	50	0	0
Pliocene Fauna of St. Erth	50	0	0
Carboniferous Flora of Lancashire and West Yorkshire	25	0	0
Volcanic Phenomena of Vesuvius	20	0	0
Zoology and Botany of West Indies	100	0	0
Flora of Bahamas	100	0	0
Development of Fishes—St. Andrews	50	0	0
Marine Laboratory, Plymouth	100	0	0
Migration of Birds	30	0	0
Flora of China	75	0	0
Naples Zoological Station	100	0	0
Lymphatic System	25	0	0
Biological Station at Granton	50	0	0
Peradeniya Botanical Station	50	0	0
Development of Teleostei	15	0	0
Depth of Frozen Soil in Polar Regions	5	0	0
Precious Metals in Circulation	20	0	0
Value of Monetary Standard	10	0	0
Effect of Occupations on Physical Development	25	0	0
North-Western Tribes of Canada	100	0	0
Prehistoric Race in Greek Islands	20	0	0
	£1511	0	5

1889.

	£	s.	d.
Ben Nevis Observatory	50	0	0
Electrical Standards	75	0	0
Electrolysis	20	0	0
Surface Water Temperature	30	0	0
Silent Discharge of Electricity on Oxygen	6	4	8
Methods of teaching Chemistry	10	0	0
Action of Light on Hydracids	10	0	0
Geological Record	80	0	0
Volcanic Phenomena of Japan	25	0	0
Volcanic Phenomena of Vesuvius	20	0	0
Palæozoic Phyllopoda	20	0	0
Higher Eocene Beds of Isle of Wight	15	0	0
West Indian Explorations	100	0	0
Flora of China	25	0	0
Naples Zoological Station	100	0	0
Physiology of Lymphatic System	25	0	0
Experiments with a Tow-net	5	16	3
Natural History of Friendly Islands	100	0	0
Geology and Geography of Atlas Range	100	0	0
Action of Waves and Currents in Estuaries	100	0	0
North-Western Tribes of Canada	150	0	0
Nomad Tribes of Asia Minor	30	0	0
Corresponding Societies	20	0	0
Marine Biological Association	200	0	0
'Baths Committee,' Bath	100	0	0
	£1417	0	11

1890.

	£	s.	d.
Electrical Standards	12	17	0
Electrolysis	5	0	0
Electro-optics	50	0	0
Mathematical Tables	25	0	0
Volcanic and Seismological Phenomena of Japan	75	0	0
Pellian Equation Tables	15	0	0
Properties of Solutions	10	0	0
International Standard for the Analysis of Iron and Steel	10	0	0
Influence of the Silent Discharge of Electricity on Oxygen	5	0	0
Methods of teaching Chemistry	10	0	0
Recording Results of Water Analysis	4	1	0
Oxidation of Hydracids in Sunlight	15	0	0
Volcanic Phenomena of Vesuvius	20	0	0
Palæozoic Phyllopoda	10	0	0
Circulation of Underground Waters	5	0	0
Excavations at Oldbury Hill	15	0	0
Cretaceous Polyzoa	10	0	0
Geological Photographs	7	14	11
Lias Beds of Northampton	25	0	0
Botanical Station at Peradeniya	25	0	0

	£	s.	d.
Experiments with a Tow-net	4	3	9
Naples Zoological Station	100	0	0
Zoology and Botany of the West India Islands	100	0	0
Marine Biological Association	30	0	0
Action of Waves and Currents in Estuaries	150	0	0
Graphic Methods in Mechanical Science	11	0	0
Anthropometric Calculations	5	0	0
Nomad Tribes of Asia Minor	25	0	0
Corresponding Societies	20	0	0
	£799	16	8

1891.

	£	s.	d.
Ben Nevis Observatory	50	0	0
Electrical Standards	100	0	0
Electrolysis	5	0	0
Seismological Phenomena of Japan	10	0	0
Temperatures of Lakes	20	0	0
Photographs of Meteorological Phenomena	5	0	0
Discharge of Electricity from Points	10	0	0
Ultra Violet Rays of Solar Spectrum	50	0	0
International Standard for Analysis of Iron and Steel	10	0	0
Isomeric Naphthalene Derivatives	25	0	0
Formation of Haloids	25	0	0
Action of Light on Dyes	17	10	0
Geological Record	100	0	0
Volcanic Phenomena of Vesuvius	10	0	0
Fossil Phyllopoda	10	0	0
Photographs of Geological Interest	9	5	0
Lias of Northamptonshire	25	0	0
Registration of Type-Specimens of British Fossils	5	5	0
Investigation of Elbolton Cave	25	0	0
Botanical Station at Peradeniya	50	0	0
Experiments with a Tow-net	40	0	0
Marine Biological Association	12	10	0
Disappearance of Native Plants	5	0	0
Action of Waves and Currents in Estuaries	125	0	0
Anthropometric Calculations	10	0	0
New Edition of 'Anthropological Notes and Queries'	50	0	0
North-Western Tribes of Canada	200	0	0
Corresponding Societies	25	0	0
	£1029	10	0

1892.

	£	s.	d.
Observations on Ben Nevis	50	0	0
Photographs of Meteorological Phenomena	15	0	0
Pellian Equation Tables	10	0	0
Discharge of Electricity from Points	50	0	0
Seismological Phenomena of Japan	10	0	0
Formation of Haloids	12	0	0
Properties of Solutions	10	0	0
Action of Light on Dyed Colours	10	0	0
Erratic Blocks	15	0	0
Photographs of Geological Interest	20	0	0
Underground Waters	10	0	0
Investigation of Elbolton Cave	25	0	0
Excavations at Oldbury Hill	10	0	0
Cretaceous Polyzoa	10	0	0
Naples Zoological Station	100	0	0
Marine Biological Association	17	10	0
Deep-sea Tow-net	40	0	0
Fauna of Sandwich Islands	100	0	0
Zoology and Botany of West India Islands	100	0	0
Climatology and Hydrography of Tropical Africa	50	0	0
Anthropometric Laboratory	5	0	0
Anthropological Notes and Queries	20	0	0
Prehistoric Remains in Mashonaland	50	0	0
North-Western Tribes of Canada	100	0	0
Corresponding Societies	25	0	0
	£864	10	0

1893.

	£	s.	d.
Electrical Standards	25	0	0
Observations on Ben Nevis	150	0	0
Mathematical Tables	15	0	0
Intensity of Solar Radiation	2	8	6
Magnetic Work at the Falmouth Observatory	25	0	0
Isomeric Naphthalene Derivatives	20	0	0
Erratic Blocks	10	0	0
Fossil Phyllopoda	5	0	0
Underground Waters	5	0	0
Shell-bearing Deposits at Clava, Chapelhall, &c.	20	0	0
Eurypterids of the Pentland Hills	10	0	0
Naples Zoological Station	100	0	0
Marine Biological Association	30	0	0
Fauna of Sandwich Islands	100	0	0
Zoology and Botany of West India Islands	50	0	0

	£	s.	d.
Exploration of Irish Sea	30	0	0
Physiological Action of Oxygen in Asphyxia	20	0	0
Index of Genera and Species of Animals	20	0	0
Exploration of Karakoram Mountains	50	0	0
Scottish Place-names	7	0	0
Climatology and Hydrography of Tropical Africa	50	0	0
Economic Training	3	7	0
Anthropometric Laboratory...	5	0	0
Exploration in Abyssinia......	25	0	0
North-Western Tribes of Canada	100	0	0
Corresponding Societies	30	0	0
	£907	15	6

1894.

	£	s.	d.
Electrical Standards...........	25	0	0
Photographs of Meteorological Phenomena	10	0	0
Tables of Mathematical Functions	15	0	0
Intensity of Solar Radiation	5	5	6
Wave-length Tables	10	0	0
Action of Light upon Dyed Colours	5	0	0
Erratic Blocks	15	0	0
Fossil Phyllopoda	5	0	0
Shell-bearing Deposits at Clava, &c.	20	0	0
Eurypterids of the Pentland Hills...........................	5	0	0
New Sections of Stonesfield Slate	14	0	0
Observations on Earth Tremors	50	0	0
Exploration of Calf-Hole Cave...........................	5	0	0
Naples Zoological Station ...	100	0	0
Marine Biological Association	5	0	0
Zoology of the Sandwich Islands	100	0	0
Zoology of the Irish Sea	40	0	0
Structure and Function of the Mammalian Heart...........	10	0	0
Exploration in Abyssinia ...	30	0	0
Economic Training	9	10	0
Anthropometric Laboratory Statistics........................	5	0	0
Ethnographical Survey	10	0	0
The Lake Village at Glastonbury............................	40	0	0
Anthropometrical Measurements in Schools	5	0	0
Mental and Physical Condition of Children...............	20	0	0
Corresponding Societies	25	0	0
	£583	15	6

1895.

	£	s.	d.
Electrical Standards...........	5	0	0
Photographs of Meteorological Phenomena	10	0	0
Earth Tremors	75	0	0
Abstracts of Physical Papers	100	0	0
Reduction of Magnetic Observations made at Falmouth Observatory	50	0	0
Comparison of Magnetic Standards	25	0	0
Meteorological Observations on Ben Nevis	50	0	0
Wave-length Tables of the Spectra of the Elements ...	10	0	0
Action of Light upon Dyed Colours	4	6	1
Formation of Haloids from Pure Materials	20	0	0
Isomeric Naphthalene Derivatives..........................	30	0	0
Electrolytic Quantitative Analysis	30	0	0
Erratic Blocks	10	0	0
Palæozoic Phyllopoda	5	0	0
Photographs of Geological Interest	10	0	0
Shell-bearing Deposits at Clava, &c.	10	0	0
Eurypterids of the Pentland Hills............................	3	0	0
New Sections of Stonesfield Slate	50	0	0
Exploration of Calf Hole Cave	10	0	0
Nature and Probable Age of High-level Flint-drifts	10	0	0
Table at the Zoological Station at Naples	100	0	0
Table at the Biological Laboratory, Plymouth	15	0	0
Zoology, Botany, and Geology of the Irish Sea..............	35	9	4
Zoology and Botany of the West India Islands	50	0	0
Index of Genera and Species of Animals	50	0	0
Climatology of Tropical Africa	5	0	0
Exploration of Hadramut ...	50	0	0
Calibration and Comparison of Measuring Instruments ...	25	0	0
Anthropometric Measurements in Schools	5	0	0
Lake Village at Glastonbury	30	0	0
Exploration of a Kitchen-midden at Hastings	10	0	0
Ethnographical Survey	10	0	0
Physiological Applications of the Phonograph..............	25	0	0
Corresponding Societies	30	0	0
	£977	15	5

1896.

	£	s.	d.
Photographs of Meteorological Phenomena	15	0	0
Seismological Observations	80	0	0
Abstracts of Physical Papers	100	0	0
Calculation of certain Integrals	10	0	0
Uniformity of Size of Pages of Transactions, &c.	5	0	0
Wave-length Tables of the Spectra of the Elements	10	0	0
Action of Light upon Dyed Colours	2	6	1
Electrolytic Quantitative Analysis	10	0	0
The Carbohydrates of Barley Straw	50	0	0
Reprinting Discussion on the Relation of Agriculture to Science	5	0	0
Erratic Blocks	10	0	0
Palæozoic Phyllopoda	5	0	0
Shell-bearing Deposits at Clava, &c.	10	0	0
Eurypterids of the Pentland Hills	2	0	0
Investigation of a Coral Reef by Boring and Sounding	10	0	0
Examination of Locality where the Cetiosaurus in the Oxford Museum was found	25	0	0
Palæolithic Deposits at Hoxne	25	0	0
Fauna of Singapore Caves	40	0	0
Age and Relation of Rocks near Moreseat, Aberdeen	10	0	0
Table at the Zoological Station at Naples	100	0	0
Table at the Biological Laboratory, Plymouth	15	0	0
Zoology, Botany, and Geology of the Irish Sea	50	0	0
Zoology of the Sandwich Islands	100	0	0
African Lake Fauna	100	0	0
Oysters under Normal and Abnormal Environment	40	0	0
Climatology of Tropical Africa	10	0	0
Calibration and Comparison of Measuring Instruments	20	0	0
Small Screw Gauge	10	0	0
North-Western Tribes of Canada	100	0	0
Lake Village at Glastonbury	30	0	0
Ethnographical Survey	40	0	0
Mental and Physical Condition of Children	10	0	0
Physiological Applications of the Phonograph	25	0	0
Corresponding Societies Committee	30	0	0
	£1104	6	1

1897.

	£	s.	d.
Mathematical Tables	25	0	0
Seismological Observations	100	0	0
Abstracts of Physical Papers	100	0	0
Calculation of certain Integrals	10	0	0
Electrolysis and Electro-chemistry	50	0	0
Electrolytic Quantitative Analysis	10	0	0
Isomeric Naphthalene Derivatives	50	0	0
Erratic Blocks	10	0	0
Photographs of Geological Interest	15	0	0
Remains of the Irish Elk in the Isle of Man	15	0	0
Table at the Zoological Station, Naples	100	0	0
Table at the Biological Laboratory, Plymouth	9	10	8
Zoological Bibliography and Publication	5	0	0
Index Generum et Specierum Animalium	100	0	0
Zoology and Botany of the West India Islands	40	0	0
The Details of Observations on the Migration of Birds	40	0	0
Climatology of Tropical Africa	20	0	0
Ethnographical Survey	40	0	0
Mental and Physical Condition of Children	10	0	0
Silchester Excavation	20	0	0
Investigation of Changes associated with the Functional Activity of Nerve Cells and their Peripheral Extensions	180	0	0
Oysters and Typhoid	30	0	0
Physiological Applications of the Phonograph	15	0	0
Physiological Effects of Peptone and its Precursors	20	0	0
Fertilisation in Phæophyceæ	20	0	0
Corresponding Societies Committee	25	0	0
	£1059	10	8

1898.

	£	s.	d.
Electrical Standards	75	0	0
Seismological Observations	75	0	0
Abstracts of Physical Papers	100	0	0
Calculation of certain Integrals	10	0	0
Electrolysis and Electro-chemistry	35	0	0
Meteorological Observatory at Montreal	50	0	0

	£	s.	d.
Wave-length Tables of the Spectra of the Elements	20	0	0
Action of Light upon Dyed Colours	8	0	0
Erratic Blocks	5	0	0
Investigation of a Coral Reef	40	0	0
Photographs of Geological Interest	10	0	0
Life-zones in British Carboniferous Rocks	15	0	0
Pleistocene Fauna and Flora in Canada	20	0	0
Table at the Zoological Station, Naples	100	0	0
Table at the Biological Laboratory, Plymouth	14	0	0
Index Generum et Specierum Animalium	100	0	0
Healthy and Unhealthy Oysters	30	0	0
Climatology of Tropical Africa	10	0	0
State Monopolies in other Countries	15	0	0
Small Screw Gauge	20	0	0
North-Western Tribes of Canada	75	0	0
Lake Village at Glastonbury	37	10	0
Silchester Excavation	7	10	0
Ethnological Survey of Canada	75	0	0
Anthropology and Natural History of Torres Straits	125	0	0
Investigation of Changes associated with the Functional Activity of Nerve Cells and their Peripheral Extensions	100	0	0
Fertilisation in Phæophyceæ	15	0	0
Corresponding Societies Committee	25	0	0
	£1212	0	0

1899.

	£	s.	d.
Electrical Standards	225	0	0
Seismological Observations	65	14	8
Science Abstracts	100	0	0
Heat of Combination of Metals in Alloys	20	0	0
Radiation in a Magnetic Field	50	0	0
Calculation of certain Integrals	10	0	0
Action of Light upon Dyed Colours	4	19	6
Relation between Absorption Spectra and Constitution of Organic Substances	50	0	0
Erratic Blocks	15	0	0
Photographs of Geological Interest	10	0	0
Remains of Irish Elk in the Isle of Man	15	0	0
Pleistocene Flora and Fauna in Canada	30	0	0
Records of Disappearing Drift Section at Moel Tryfaen	5	0	0
Ty Newydd Caves	40	0	0
Ossiferous Caves at Uphill	30	0	0
Table at the Zoological Station, Naples	100	0	0
Table at the Biological Laboratory, Plymouth	20	0	0
Index Generum et Specierum Animalium	100	0	0
Migration of Birds	15	0	0
Apparatus for Keeping Aquatic Organisms under Definite Physical Conditions	15	0	0
Plankton and Physical Conditions of the English Channel during 1899	100	0	0
Exploration of Sokotra	35	0	0
Lake Village at Glastonbury	50	0	0
Silchester Excavation	10	0	0
Ethnological Survey of Canada	35	0	0
New Edition of 'Anthropological Notes and Queries'	40	0	0
Age of Stone Circles	20	0	0
Physiological Effects of Peptone	30	0	0
Electrical Changes accompanying Discharge of Respiratory Centres	20	0	0
Influence of Drugs upon the Vascular Nervous System	10	0	0
Histological Changes in Nerve Cells	20	0	0
Micro-chemistry of Cells	40	0	0
Histology of Suprarenal Capsules	20	0	0
Comparative Histology of Cerebral Cortex	10	0	0
Fertilisation in Phæophyceæ	20	0	0
Assimilation in Plants	20	0	0
Zoological and Botanical Publication	5	0	0
Corresponding Societies Committee	25	0	0
	£1430	14	2

1900.

	£	s.	d.
Electrical Standards	25	0	0
Seismological Observations	60	0	0
Radiation in a Magnetic Field	25	0	0
Meteorological Observatory at Montreal	20	0	0
Tables of Mathematical Functions	75	0	0
Relation between Absorption Spectra and Constitution of Organic Bodies	30	0	0
Wave-length Tables	5	0	0
Electrolytic Quantitative Analysis	5	0	0

	£	s.	d.
Isomorphous Sulphonic Derivatives of Benzene	20	0	0
The Nature of Alloys	30	0	0
Photographs of Geological Interest	10	0	0
Remains of Elk in the Isle of Man	5	0	0
Pleistocene Fauna and Flora in Canada	10	0	0
Movements of Underground Waters of Craven	40	0	0
Table at the Zoological Station, Naples	100	0	0
Table at the Biological Laboratory, Plymouth	20	0	0
Index Generum et Specierum Animalium	50	0	0
Migration of Birds	15	0	0
Plankton and Physical Conditions of the English Channel	40	0	0
Zoology of the Sandwich Islands	100	0	0
Coral Reefs of the Indian Region	30	0	0
Physical and Chemical Constants of Sea-Water	100	0	0
Future Dealings in Raw Produce	2	10	0
Silchester Excavation	10	0	0
Ethnological Survey of Canada	50	0	0
New Edition of 'Anthropological Notes and Queries'	40	0	0
Photographs of Anthropological Interest	10	0	0
Mental and Physical Condition of Children in Schools	5	0	0
Ethnography of the Malay Peninsula	25	0	0
Physiological Effects of Peptone	20	0	0
Comparative Histology of Suprarenal Capsules	20	0	0
Comparative Histology of Cerebral Cortex	5	0	0
Electrical Changes in Mammalian Nerves	20	0	0
Vascular Supply of Secreting Glands	10	0	0
Fertilisation in Phæophyceæ	20	0	0
Corresponding Societies Committee	20	0	0
	£1072	10	0

1901.

	£	s.	d.
Electrical Standards	45	0	0
Seismological Observations	75	0	0
Wave-length Tables	4	14	0
Isomorphous Sulphonic Derivatives of Benzene	35	0	0
Life-zones in British Carboniferous Rocks	20	0	0
Underground Water of North-west Yorkshire	50	0	0
Exploration of Irish Caves	15	0	0
Table at the Zoological Station, Naples	100	0	0
Table at the Biological Laboratory, Plymouth	20	0	0
Index Generum et Specierum Animalium	75	0	0
Migration of Birds	10	0	0
Terrestrial Surface Waves	5	0	0
Changes of Land-level in the Phlegræan Fields	50	0	0
Legislation regulating Women's Labour	15	0	0
Small Screw Gauge	45	0	0
Resistance of Road Vehicles to Traction	75	0	0
Silchester Excavation	10	0	0
Ethnological Survey of Canada	30	0	0
Anthropological Teaching	5	0	0
Exploration in Crete	145	0	0
Physiological Effects of Peptone	30	0	0
Chemistry of Bone Marrow	5	15	11
Suprarenal Capsules in the Rabbit	5	0	0
Fertilisation in Phæophyceæ	15	0	0
Morphology, Ecology, and Taxonomy of Podostemaceæ	20	0	0
Corresponding Societies Committee	15	0	0
	£920	9	11

1902.

	£	s.	d.
Electrical Standards	40	0	0
Seismological Observations	35	0	0
Investigation of the Upper Atmosphere by means of Kites	75	0	0
Magnetic Observations at Falmouth	80	0	0
Relation between Absorption Spectra and Organic Substances	20	0	0
Wave-length Tables	5	0	0
Life-zones in British Carboniferous Rocks	10	0	0
Exploration of Irish Caves	45	0	0
Table at the Zoological Station, Naples	100	0	0
Index Generum et Specierum Animalium	100	0	0
Migration of Birds	15	0	0
Structure of Coral Reefs of Indian Ocean	50	0	0

	£	s.	d.
Compound Ascidians of the Clyde Area	25	0	0
Terrestrial Surface Waves	15	0	0
Legislation regulating Women's Labour	30	0	0
Small Screw Gauge	20	0	0
Resistance of Road Vehicles to Traction	50	0	0
Ethnological Survey of Canada	15	0	0
Age of Stone Circles	30	0	0
Exploration in Crete	100	0	0
Anthropometric Investigation of Native Egyptian Soldiers	15	0	0
Excavations on the Roman Site at Gelligaer	5	0	0
Changes in Hæmoglobin	15	0	0
Work of Mammalian Heart under Influence of Drugs	20	0	0
Investigation of the Cyanophyceæ	10	0	0
Reciprocal Influence of Universities and Schools	5	0	0
Conditions of Health essential to carrying on Work in Schools	2	0	0
Corresponding Societies Committee	15	0	0
	£947	0	0

1903.

	£	s.	d.
Electrical Standards	35	0	0
Seismological Observations	40	0	0
Investigation of the Upper Atmosphere by means of Kites	75	0	0
Magnetic Observations at Falmouth	40	0	0
Study of Hydro-aromatic Substances	20	0	0
Erratic Blocks	10	0	0
Exploration of Irish Caves	40	0	0
Underground Waters of North-west Yorkshire	40	0	0
Life-zones in British Carboniferous Rocks	5	0	0
Geological Photographs	10	0	0
Table at the Zoological Station at Naples	100	0	0
Index Generum et Specierum Animalium	100	0	0
Tidal Bore, Sea Waves, and Beaches	15	0	0
Scottish National Antarctic Expedition	50	0	0
Legislation affecting Women's Labour	25	0	0
Researches in Crete	100	0	0
Age of Stone Circles	3	13	2
Anthropometric Investigation	5	0	0
Anthropometry of the Todas and other Tribes of Southern India	50	0	0
The State of Solution of Proteids	20	0	0
Investigation of the Cyanophyceæ	25	0	0
Respiration of Plants	12	0	0
Conditions of Health essential for School Instruction	5	0	0
Corresponding Societies Committee	20	0	0
	£845	13	2

1904.

	£	s.	d.
Seismological Observations	40	0	0
Investigation of the Upper Atmosphere by means of Kites	50	0	0
Magnetic Observations at Falmouth	60	0	0
Wave length Tables of Spectra	10	0	0
Study of Hydro-aromatic Substances	25	0	0
Erratic Blocks	10	0	0
Life-zones in British Carboniferous Rocks	35	0	0
Fauna and Flora of the Trias	10	0	0
Investigation of Fossiliferous Drifts	50	0	0
Table at the Zoological Station, Naples	100	0	0
Index Generum et Specierum Animalium	60	0	0
Development in the Frog	15	0	0
Researches on the Higher Crustacea	15	0	0
British and Foreign Statistics of International Trade	25	0	0
Resistance of Road Vehicles to Traction	90	0	0
Researches in Crete	100	0	0
Researches in Glastonbury Lake Village	25	0	0
Anthropometric Investigation of Egyptian Troops	8	10	0
Excavations on Roman Sites in Britain	25	0	0
The State of Solution of Proteids	20	0	0
Metabolism of Individual Tissues	40	0	0
Botanical Photographs	4	8	11
Respiration of Plants	15	0	0
Experimental Studies in Heredity	35	0	0
Corresponding Societies Committee	20	0	0
	£887	8	11

1905.

	£	s.	d.
Electrical Standards	40	0	0
Seismological Observations	40	0	0
Investigation of the Upper Atmosphere by means of Kites	40	0	0
Magnetic Observations at Falmouth	50	0	0
Wave-length Tables of Spectra	5	0	0
Study of Hydro-aromatic Substances	25	0	0
Dynamic Isomerism	20	0	0
Aromatic Nitramines	25	0	0
Fauna and Flora of the British Trias	10	0	0
Table at the Zoological Station, Naples	100	0	0
Index Generum et Specierum Animalium	75	0	0
Development of the Frog	10	0	0
Investigations in the Indian Ocean	150	0	0
Trade Statistics	4	4	8
Researches in Crete	75	0	0
Anthropometric Investigations of Egyptian Troops	10	0	0
Excavations on Roman Sites in Britain	10	0	0
Anthropometric Investigations	10	0	0
Age of Stone Circles	30	0	0
The State of Solution of Proteids	20	0	0
Metabolism of Individual Tissues	30	0	0
Ductless Glands	40	0	0
Botanical Photographs	3	17	6
Physiology of Heredity	35	0	0
Structure of Fossil Plants	50	0	0
Corresponding Societies Committee	20	0	0
	£928	2	2

1906.

	£	s.	d.
Electrical Standards	25	0	0
Seismological Observations	40	0	0
Magnetic Observations at Falmouth	50	0	0
Magnetic Survey of South Africa	99	12	6
Wave-length Tables of Spectra	5	0	0
Study of Hydro-aromatic Substances	25	0	0
Aromatic Nitramines	10	0	0
Fauna and Flora of the British Trias	7	8	11
Crystalline Rocks of Anglesey	30	0	0
Table at the Zoological Station, Naples	100	0	0
Index Animalium	75	0	0
Development of the Frog	10	0	0
Higher Crustacea	15	0	0
Freshwater Fishes of South Africa	50	0	0
Rainfall and Lake and River Discharge	10	0	0
Excavations in Crete	100	0	0
Lake Village at Glastonbury	40	0	0
Excavations on Roman Sites in Britain	30	0	0
Anthropometric Investigations in the British Isles	30	0	0
State of Solution of Proteids	20	0	0
Metabolism of Individual Tissues	20	0	0
Effect of Climate upon Health and Disease	20	0	0
Research on South African Cycads	14	19	4
Peat Moss Deposits	25	0	0
Studies suitable for Elementary Schools	5	0	0
Corresponding Societies Committee	25	0	0
	£882	0	9

1907.

	£	s.	d.
Electrical Standards	50	0	0
Seismological Observations	40	0	0
Magnetic Observations at Falmouth	40	0	0
Magnetic Survey of South Africa	25	7	6
Wave-length Tables of Spectra	10	0	0
Study of Hydro-aromatic Substances	30	0	0
Dynamic Isomerism	30	0	0
Life Zones in British Carboniferous Rocks	10	0	0
Erratic Blocks	10	0	0
Fauna and Flora of British Trias	10	0	0
Faunal Succession in the Carboniferous Limestone of South-West England	15	0	0
Correlation and Age of South African Strata, &c.	10	0	0
Table at the Zoological Station, Naples	100	0	0
Index Animalium	75	0	0
Development of the Sexual Cells	1	11	8
Oscillations of the Land Level in the Mediterranean Basin	50	0	0
Gold Coinage in Circulation in the United Kingdom	8	19	7
Anthropometric Investigations in the British Isles	10	0	0
Metabolism of Individual Tissues	45	0	0
The Ductless Glands	25	0	0
Effect of Climate upon Health and Disease	55	0	0

	£	s.	d.
Physiology of Heredity	30	0	0
Research on South African Cycads..........................	35	0	0
Botanical Photographs.........	5	0	0
Structure of Fossil Plants ...	5	0	0
Marsh Vegetation...............	15	0	0
Corresponding Societies Committee..........................	16	14	1
	£757	12	10

1908.

	£	s.	d.
Seismological Observations ...	40	0	0
Further Tabulation of Bessel Functions	15	0	0
Investigation of Upper Atmosphere by means of Kites...	25	0	0
Meteorological Observations on Ben Nevis...........	25	0	0
Geodetic Arc in Africa.........	200	0	0
Wave-length Tables of Spectra	10	0	0
Study of Hydro-aromatic Substances..........................	30	0	0
Dynamic Isomerism	40	0	0
Transformation of Aromatic Nitramines	30	0	0
Erratic Blocks	17	16	6
Fauna and Flora of British Trias	10	0	0
Faunal Succession in the Carboniferous Limestone in the British Isles	10	0	0
Pre-Devonian Rocks............	10	0	0
Exact Significance of Local Terms	5	0	0
Composition of Charnwood Rocks	10	0	0
Table at the Zoological Station at Naples.......................	100	0	0
Index Animalium	75	0	0
Hereditary Experiments	10	0	0
Fauna of Lakes of Central Tasmania	40	0	0
Investigations in the Indian Ocean	50	0	0
Exploration in Spitsbergen ...	30	0	0
Gold Coinage in Circulation in the United Kingdom......	3	7	6
Electrical Standards	50	0	0
Glastonbury Lake Village ...	30	0	0
Excavations on Roman Sites in Britain	15	0	0
Age of Stone Circles...........	50	0	0
Anthropological Notes and Queries	40	0	0
Metabolism of Individual Tissues..........................	40	0	0
The Ductless Glands...........	13	14	8
Effect of Climate upon Health and Disease....................	35	0	0
Body Metabolism in Cancer...	30	0	0
Electrical Phenomena and Metabolism of *Arum Spadices*	10	0	0
Marsh Vegetation	15	0	0
Succession of Plant Remains	18	0	0
Corresponding Societies Committee	25	0	0
	£1157	18	8

1909.

	£	s.	d.
Seismological Observations ..	60	0	0
Investigation of the Upper Atmosphere by means of Kites	10	0	0
Magnetic Observations at Falmouth	50	0	0
Establishing a Solar Observatory in Australia	50	0	0
Wave-length Tables of Spectra	9	16	0
Study of Hydro-aromatic Substances	15	0	0
Dynamic Isomerism...........	35	0	0
Transformation of Aromatic Nitramines......................	10	0	0
Electroanalysis	30	0	0
Fauna and Flora of British Trias	8	0	0
Faunal Succession in the Carboniferous Limestone in the British Isles	8	0	0
Palæozoic Rocks of Wales and the West of England	9	0	0
Igneous and Associated Sedimentary Rocks of Glensaul	11	13	9
Investigations at Biskra	50	0	0
Table at the Zoological Station at Naples	100	0	0
Heredity Experiments.........	10	0	0
Feeding Habits of British Birds	5	0	0
Index Animalium..............	75	0	0
Investigations in the Indian Ocean	35	0	0
Gaseous Explosions	75	0	0
Excavations on Roman Sites in Britain	5	0	0
Age of Stone Circles............	30	0	0
Researches in Crete	70	0	0
The Ductless Glands	35	0	0
Electrical Phenomena and Metabolism of *Arum Spadices*	10	0	0
Reflex Muscular Rhythm......	10	0	0
Anæsthetics	25	0	0
Mental and Muscular Fatigue	27	0	0
Structure of Fossil Plants ...	5	0	0
Botanical Photographs.........	10	0	0
Experimental Study of Heredity.......................	30	0	0
Symbiosis between Turbellarian Worms and Algæ	10	0	0
Survey of Clare Island.........	65	0	0
Curricula of Secondary Schools	5	0	0
Corresponding Societies Committee	21	0	0
	£1014	9	9

1910.	£	s.	d.
Measurement of Geodetic Arc in South Africa	100	0	0
Republication of Electrical Standards Report s	100	0	0
Seismological Observations	60	0	0
Magnetic Observations at Falmouth	25	0	0
Investigation of the Upper Atmosphere	25	0	0
Study of Hydro-aromatic Substances	25	0	0
Dynamic Isomerism	35	0	0
Transformation of Aromatic Nitro-amines	15	0	0
Electroanalysis	10	0	0
Faunal Succession in the Carboniferous Limestone in the British Isles	10	0	0
South African Strata	5	0	0
Fossils of Midland Coalfields	25	0	0
Table at the Zoological Station at Naples	100	0	0
Index Animalium	75	0	0
Heredity Experiments	15	0	0
Feeding Habits of British Birds	5	0	0
Amount and Distribution of Income	15	0	0
Gaseous Explosions	75	0	0
Lake Villages in the neighbourhood of Glastonbury	5	0	0
Excavations on Roman Sites in Britain	5	0	0
Neolithic Sites in Northern Greece	5	0	0
The Ductless Glands	40	0	0
Body Metabolism in Cancer	20	0	0
Anæsthetics	25	0	0
Tissue Metabolism	25	0	0
Mental and Muscular Fatigue	18	17	0
Electromotive Phenomena in Plants	10	0	0
Structure of Fossil Plants	10	0	0
Experimental Study of Heredity	30	0	0
Survey of Clare Island	30	0	0
Corresponding Societies Committee	20	0	
	£963	17	0

REPORT OF THE COUNCIL, 1909-1910.

I. The Council resolved to present the following Address to His Majesty the King on his accession to the Throne:—

To THE KING'S MOST EXCELLENT MAJESTY.

May it please Your Majesty,—We, the President and Council of the British Association for the Advancement of Science, most respectfully desire to be permitted to express to Your Majesty our deepest sympathy in the great loss which Your Majesty and the Empire have sustained in the death of your august Father, King Edward VII.

The British Association bears in grateful remembrance the fact that your illustrious Grandfather, His Royal Highness the Prince Consort, to whose scientific knowledge and wise guidance the nation owes much, accepted the office of President of the Association for the Meeting held at Aberdeen in 1859. We would also gratefully record that more recently your Father, the late King, was pleased, in 1904, to accede to the request that he should honour the Association by becoming its Patron.

We beg to be permitted to offer to Your Majesty the humble expression of our sincere congratulation and loyal homage and devotion on your succession to the Throne of your Ancestors, and we confidently hope that the progress of Science during the reign of Your Majesty will continue to promote the prosperity of your people throughout the Empire.

Signed on behalf of the Council,
J. J. THOMSON,
President.

To this Address the following reply was received:—

Home Office, Whitehall: *June 30th*, 1910

SIR,—I am commanded by the King to convey to you hereby His Majesty's thanks for the loyal and dutiful Address of the President and Council of the British Association for the Advancement of Science expressing their sympathy with His Majesty on the occasion of the lamented death of his late Majesty King Edward the Seventh, and congratulation on His Majesty's Accession to the Throne.

I am, Sir,
Your obedient servant,
(Signed) WINSTON S. CHURCHILL.

SIR J. J. THOMSON, F.R.S.

The Council further desired the President to forward the following letter:—

LIEUT.-COL. SIR ARTHUR J. BIGGE, K.C.M.G., G.C.V.O., &c., &c.

SIR,—I have the honour to inform you that the Council of the British Association for the Advancement of Science have voted a humble Address of sympathy and congratulation to His Majesty the King.

The Address refers gratefully to the honour which King Edward VII. conferred upon the Association by becoming its Patron in 1904. The

Council, in voting the Address, directed me to express the respectful hope that His Majesty may be graciously pleased to follow his august Father in the Patronage of the Association.

I have the honour to be, Sir,

Your obedient Servant,

(*Signed*) J. J. Thomson,

President of the British Association.

The following gracious reply was received:—

Marlborough House, Pall Mall, S.W.

Dear Sir,—I am commanded by the King to inform you that His Majesty is graciously pleased to become Patron of the British Association for the Advancement of Science.

Yours faithfully,

(*Signed*) W. Carington,

Keeper of His Majesty's Privy Purse.

II. Sir William Ramsay, K.C.B., F.R.S., has been unanimously nominated by the Council to fill the office of President of the Association for 1911 (Portsmouth Meeting).

III. The following Nominations are made by the Council:—

Conference of Delegates.—Dr. Tempest Anderson (*Chairman*), Professor P. F. Kendall (*Vice-Chairman*), Mr. W. P. D. Stebbing (*Secretary*).

Corresponding Societies Committee.—Mr. W. Whitaker (*Chairman*), Mr. W. P. D. Stebbing (*Secretary*), Rev. J. O. Bevan, Sir Edward Brabrook, Dr. J. G. Garson, Dr. E. H. Griffiths, Dr. A. C. Haddon, Mr. T. V. Holmes, Mr. J. Hopkinson, Mr. A. L. Lewis, Mr. F. W. Rudler, Rev. T. R. R. Stebbing.

IV. A Report has been received from the Corresponding Societies Committee, together with the list of the Corresponding Societies, and the titles of the more important papers published by the Societies during the year ending May 31, 1910.

V. The following Resolutions were formulated by the General Committee at Winnipeg and referred to the Council:—

(i) 'That the Council be asked to consider the relationship of the Sections generally, and the possible desirability of a new subdivision and the incorporation of new subjects.

(ii) 'That in any revision of the organisation of the Association full recognition be given to the importance of Agricultural Science.'

The Council resolved that a Committee be appointed, with the following terms of reference:—

To consider and report to the Council on the relationship of the Sections generally, and the possible desirability of a new subdivision and the incorporation of new subjects, and to make recommendations on other matters arising therefrom, the Committee being empowered to confer with Members of the Association outside its own body, if necessary.

The following were appointed to serve on the Committee:—

The President, General Officers, and President-Elect, with

Prof. H. E. Armstrong.	Prof. F. Gotch.
Sir Edward Brabrook.	E. Sidney Hartland.
Sir Lauder Brunton.	Dr. J. Scott Keltie.
Major P. G. Craigie.	Sir Oliver Lodge.
Dr. J. A. Ewing.	Prof. E. B. Poulton.
Prof. J. B. Farmer.	W. A. Price.
Dr. G. Carey Foster.	Dr. W. N. Shaw.
Sir A. Geikie.	Dr. J. J. H. Teall.
Sir D. Gill.	Sir T. E. Thorpe.
Dr. R. T. Glazebrook.	Dr. A. Smith Woodward.

The Council received the following Report from the Committee, and ordered it to be transmitted to the General Committee [note, p. cxxv.]:—

(i) The Committee recommends:—

Section A.—That the title of this Section be changed to 'Mathematics, Physics, and Astronomy (including Cosmical Physics).'

That the Council be recommended, when appointing the President of the Section, to observe, so far as possible, a rotation in the three subjects, so that Mathematics, Experimental Science, and Observational Science may be represented successively in the President.

That the official recognition of the two subjects *not* represented in the President in any one year should be ensured by the specific appointment of two of the Vice-Presidents of the Section to act as Chairman in any deliberations carried on departmentally in those subjects respectively. Departmental deliberations in each of the three subjects should, as a rule, occupy two days at most, the Sections sitting as a whole at other times.

That the Secretariat remain as at present, with one Recorder for the whole Section, and that one Secretary at least be a representative of each subject specified in the title of the Section.

(ii) The Committee has given careful consideration to the suggestion of its Executive Sub-Committee that the subjects of Geology (now Section C) and Geography (now Section E) might be combined in one Section to which the Sub-Section is attached be specifically appinted above for Section A.

The Committee, while not prepared definitely to recommend the combination of Geology and Geography—or of any other two Sections now distinct—is of opinion that this question should receive further consideration from the Council and from the General Committee.

(iii) The Committee recommends the formation of a permanent Sub-Section of Agriculture, attached to a Section to be determined by the Council annually in a certain rotation (unless the Council shall see reason to the contrary), *e.g.*, as between the Sections of Chemistry, Economic Science, and Botany.

The Committee recommends that one of the Vice-Presidents of the Section to which the Sub-section is attached be specifically appointed

as the Chairman of the Sub-Section, unless the sectional President himself represents Agriculture; that the Sub-Section have its own Recorder, and that one of the Secretaries of the Section be a representative of the Sub-Section.

As a matter arising out of the above reference, the Council caused a letter to be addressed to each Sectional Committee, urging that joint meetings and discussions on set subjects should be arranged in greater number than heretofore, and also putting forward a distribution of presidential addresses in time, in order that kindred subjects might not clash.

VI. A Resolution, referred to the Council by the General Committee at Winnipeg, has been received

From Section H:—

I.

To recommend the Council to represent to the Dominion Government:—

(i) 'That it is essential to scientific knowledge of the early history of Canada that full and accurate records should be obtained of the physical character, geographical distribution and migrations, languages, social and political institutions, native arts, industries, and economic systems of the aboriginal peoples of the country.

(ii) 'That scientific knowledge of the principles of native design and handicraft is an essential preliminary to any development of native industries such as has already been found practicable, especially in the United States, in Mexico, and in India, and that such knowledge has also proved to be of material assistance in the creation of national schools of design among the white population.

(iii) 'That, in the rapid development of the country, the native population is inevitably losing its separate existence and characteristics.

(iv) "That it is therefore of urgent importance to initiate, without delay, systematic observations and records of native physical types, languages, beliefs, and customs; and to provide for the preservation of a complete collection of examples of native arts and industries in some central institution, and for public guardianship of prehistoric monuments such as village sites, burial grounds, mounds, and rock carvings.

(v) 'That the organisation necessary to secure these objects, and to render the results of these inquiries accessible to students and to the public, is such as might easily be provided in connection with the National Museum at Ottawa, which already includes many fine examples of aboriginal arts and manufactures, and might be made a centre for the scientific study of the physical types, languages, beliefs, and customs of the aboriginal peoples."

II.

To recommend the Council to urge the Dominion Government to include in the schedules of the next Canadian Census full inquiries as to precise place of origin, native language, previous status and occupation, year of immigration, and such other information as may be deemed of scientific value for the study of the effects of the Canadian environment upon immigrants of European origin.

It was resolved that the above Resolution be adopted and forwarded to the Dominion Government, with the following covering letter:—

The Right Hon. Sir Wilfrid Laurier.

Sir,—By direction of the Council of the British Association for the Advancement of Science, we have the honour to submit the accompanying Resolution for the consideration of the Dominion Government. This Resolution was formulated by the Anthropological Section of the Association during its meeting at Winnipeg, Manitoba, in August 1909, was supported by the General Committee, and adopted by the Council.

We have the honour to be, Sir,

Your obedient Servants,

(*Signed*) J. J. Thomson, *President.*
P. A. MacMahon, W. A. Herdman, } *General Secretaries.*

Replies were received as under:—

Ottawa, *November 23rd*, 1909.

Sir,—I have the honour, by direction of the Right Honourable Sir Wilfrid Laurier, to acknowledge receipt of Resolution of the British Association for the Advancement of Science formulated by the Anthropological Section of the Association during its meeting at Winnipeg in August 1909, respecting the early history, &c., of Canada, and to state that the same will receive due consideration.

I have the honour to be, Sir,

Your obedient Servant,

(*Signed*) Rodolphe Boudreau,
Clerk of the Privy Council.

The Secretaries,
British Association for the Advancement of Science,
Burlington House,
Piccadilly, London, W.

Ottawa, *November 24th*, 1909.

Geological Survey.
R. W. Brock, *Director.*

Gentlemen,—I beg to acknowledge the receipt of a copy of the Resolution of the British Association with regard to ethnological work in Canada, which has been referred to the Geological Survey by the Privy Council.

I have to thank you for your kind interest in this matter, and trust that it may assist us in securing the necessary facilities for undertaking the work on a scale commensurate with its urgency and importance. The new National Museum will afford some of the requisite facilities.

I may say that the Government has shown appreciation of the value of the work by enabling us two years ago to make a beginning in this direction. We have an ethnologist at present living with the Esquimaux in the Arctic. A preliminary report on his observations appears in the Geological Survey Summary Report for 1908. With the assistance of the Canadian Archæological Societies and the very kind support which the British Association has given in its Resolution, I have strong hopes that something worth while may be accomplished along these lines.

I should like to take this opportunity of expressing to the British Association my profound regrets that, owing to illness, I was unable to attend the Winnipeg Meeting to meet the individual members or to personally do anything for them.

I have the honour to be, Gentlemen,

Your obedient Servant,

(*Signed*) R. W. Brock.

The Secretaries,
British Association for the Advancement of Science,
Burlington House,
Piccadilly, London, W.,
England.

It was subsequently reported to the Council by the General Officers that information had reached them that the Dominion Government of Canada had authorised the payment of the salary of an ethnologist for the Dominion, and also a grant for the collection of ethnological material. This may be regarded as a direct outcome of the representations made by the British Association.

VII. A Recommendation received by the General Committee at Winnipeg and referred to the Council was agreed to:—

That the following Committee be authorised to receive contributions from sources other than the Association:

'To conduct Explorations with a view to ascertaining the Age of Stone Circles.' (*Section H.*)

A Recommendation received by the General Committee at Winnipeg, and referred to the Council, was agreed to, amended as under:—

'That the collection of the Anthropological Photographs printed by the Anthropological Photographs Committee be, and that all further Photographs received by them may be, handed over to the custody of the Royal Anthropological Institute.' (*Section H.*)

VIII. Following a suggestion made at the Winnipeg Meeting, a list of desiderata for the Library of the University of Manitoba was obtained from the Librarian, and has been widely distributed by order of the

Council to Members of the Association and various learned Societies, with a covering letter inviting them to present to the Library any books which they might be in a position to offer. By this means a large collection of books, journals, and reprints has been presented to the Library.

IX. The Council have authorised *Section B* (Chemistry) to form a Sub-Section for Agriculture for the Sheffield Meeting, with a Chairman, Vice-Chairman, and Secretariat to deal with its transactions.

X. The Council have received reports from the General Treasurer during the past year. His Accounts from July 1, 1909, to June 30, 1910, have been audited and are presented to the General Committee.

XI. In accordance with the Regulations, the retiring Members of the Council are:—

(i) *Retiring by seniority:* Sir E. Brabrook; Dr. A. Smith Woodward.
(ii) *Retiring by least attendance:* Mr. D. G. Hogarth; the Earl of Berkeley; Sir J. Wolfe-Barry,

the Council having by a unanimous vote reversed the usual order of three members retiring by seniority and two by least attendance.

The Council nominated the following new members:—

Dr. A. C. Haddon,
Dr. J. E. Marr,
Sir W. H. White,

leaving two vacancies to be filled up by the General Committee without nomination by the Council.

XII. The General Officers have been nominated by the Council for reappointment.

XIII. Dr. O. T. Olsen has been admitted a member of the General Committee.

⁂ With reference to Section V. of the above Report, the General Committee rejected the proposals to change the title of Section A and to combine the subjects of Geology and Geography in one Section of two departments, and referred the question of a permanent Sub-Section of Agriculture back to the Council.

Dr. THE GENERAL TREASURER IN ACCOUNT
ADVANCEMENT OF SCIENCE,

1909–1910. RECEIPTS.				£	s.	d.
To Balance brought forward				542	0	9
Life Compositions (including Transfers)				294	0	0
New Annual Members' Subscriptions				364	0	0
Annual Subscriptions (including Members of American Association)				600	0	0
Sale of Associates' Tickets				776	0	0
Sale of Ladies' Tickets				89	0	0
Sale of Publications				179	1	10
Dividend on Consols				153	1	4
Dividend on India 3 per Cents.				101	14	0
Great Indian Peninsula Railway 'B' Annuity				49	3	6
Interest on Deposit Account				6	6	11
Interest on Current Account at Winnipeg Bank				12	10	0
Income Tax recovered				44	6	3
Unexpended Balances of Grants returned:—	£	s.	d.			
Botanical Photographs		8	10			
Curricula of Secondary Schools	2	15	6			
				3	4	4
				£3,214	8	11

Investments.

	£	s.	d.
$2\frac{1}{2}$ per Cent. Consolidated Stock	6,501	10	5
India 3 per Cent. Stock	3,600	0	0
£73 Great Indian Peninsula Railway 'B' Annuity (cost)	1,493	6	6
	11,594	16	11
Sir Frederick Bramwell's Gift:— $2\frac{1}{2}$ per Cent. Self-cumulating Consolidated Stock	69	4	5
	£11,664	1	4

JOHN PERRY, *General Treasurer.*

WITH THE BRITISH ASSOCIATION FOR THE *Cr.*
July 1, 1909, to June 30, 1910.

1909-1910. PAYMENTS.

	£	s.	d.	£	s.	d.
By Rent and Offices Expenses				93	17	8
Salaries, &c.				666	8	0
Printing, Binding, &c.				1,054	9	10
Special Grant for Committee on Wave-length Tables				10	0	0
Expenses of Winnipeg Meeting				275	1	2
Payment of Grants made at Winnipeg:						
Measurement of Geodetic Arc in South Africa	100	0	0			
Republication of Electrical Standards Reports	100	0	0			
Seismological Observations	60	0	0			
Magnetic Observations at Falmouth	25	0	0			
Investigation of the Upper Atmosphere	25	0	0			
Study of Hydro-aromatic Substances	25	0	0			
Dynamic Isomerism	35	0	0			
Transformation of Aromatic Nitro-amines	15	0	0			
Electroanalysis	10	0	0			
Faunal Succession in the Carboniferous Limestone in the British Isles	10	0	0			
South African Strata	5	0	0			
Fossils of Midland Coalfields	25	0	0			
Table at the Zoological Station at Naples	100	0	0			
Index Animalium	75	0	0			
Heredity Experiments	15	0	0			
Feeding Habits of British Birds	5	0	0			
Amount and Distribution of Income	15	0	0			
Gaseous Explosions	75	0	0			
Lake Villages in the neighbourhood of Glastonbury	5	0	0			
Excavations on Roman Sites in Britain	5	0	0			
Neolithic Sites in Northern Greece	5	0	0			
The Ductless Glands	40	0	0			
Body Metabolism in Cancer	20	0	0			
Anæsthetics	25	0	0			
Tissue Metabolism	25	0	0			
Mental and Muscular Fatigue	18	17	0			
Electromotive Phenomena in Plants	10	0	0			
Structure of Fossil Plants	10	0	0			
Experimental Study of Heredity	30	0	0			
Survey of Clare Island	30	0	0			
Corresponding Societies Committee	20	0	0			
				963	17	0
				£3,063	13	8
Balance at Bank of England (Western Branch)	1,149	2	1			
Add not paid in	3	15	9			
	£1,152	17	10			
Less Cheques not presented	1,006	15	3			
				146	2	7
Cash in hand				4	12	8
				£3,214	8	11

I have examined the above Account with the Books and Vouchers of the Association, and certify the same to be correct. I have also verified the Balance at the Bankers', and have ascertained that the Investments are registered in the names of the Trustees.

Approved—
EDWARD BRABROOK, } *Auditors.*
HERBERT MCLEOD, }
July 29, 1910.

W. B. KEEN, *Chartered Accountant,*
23 Queen Victoria Street, E.C.
July 27, 1910.

GENERAL MEETINGS AT SHEFFIELD.

On Wednesday, August 31, at 8.30 P.M., in the Victoria Hall Professor Sir J. J. Thomson, F.R.S., resigned the office of President to the Rev. Professor T. G. Bonney, F.R.S., who took the Chair and delivered an Address, for which see p. 3.

On Thursday, September 1, at 3.30 P.M., the Executive Committee gave a Garden Party in the Botanical Gardens; and at 8.30 P.M. the Right Hon. the Lord Mayor held a Reception at the Town Hall.

On Friday, September 2, at 8.30 P.M., in the Victoria Hall, Professor W. Stirling, M.D., delivered a Discourse on 'Types of Animal Movement' (p. 818).

On Monday, September 5, at 8.30 P.M., in the Victoria Hall, Mr. D. G. Hogarth, M.A., delivered a Discourse on 'New Discoveries about the Hittites' (p. 824).

On Tuesday, September 6, at 8.30 P.M., Receptions were held (*a*) at the University by the Chancellor of the University, and (*b*) at the Museum, Mappin Art Gallery, and Weston Park by the Reception Committee.

On Wednesday, September 7, at 3 P.M., the concluding General Meeting was held in the Old Firth College, when the following Resolutions were adopted :—

1. That a cordial vote of thanks be given to the Lord Mayor and Corporation for the reception which they had accorded to the Association.

2. That a vote of thanks be given to the Chancellor and Council of the University, the governing bodies which had granted the use of their buildings for the sectional meetings, and the authorities of the institutions and works thrown open to the inspection of the members.

3. That a vote of thanks be given to the Local Officers and Executive Committees for the admirable arrangements made for the meeting.

4. That a vote of thanks be given to the citizens of Sheffield for the generous hospitality shown to the members of the Association during the meeting.

OFFICERS OF SECTIONAL COMMITTEES PRESENT AT THE SHEFFIELD MEETING.

SECTION A.—MATHEMATICAL AND PHYSICAL SCIENCE.

President.—Prof. E. W. Hobson, F.R.S. *Vice-Presidents.*—Dr. C. Chree, F.R.S.; Dr. R. T. Glazebrook, C.B., F.R.S.; Prof. W. M. Hicks, F.R.S.; Prof. H. Lamb, F.R.S.; Prof. A. H. Leahy, M.A.; Prof. J. C. McLennan. *Secretaries.*—Prof. A. W. Porter, B.Sc. (*Recorder*); H. Bateman, M.A.; A. S. Eddington, M.A.; E. Gold, M.A.; Dr. F. Horton; Dr. S. R. Milner.

SECTION B.—CHEMISTRY.

President.—J. E. Stead, F.R.S. *Vice-Presidents.*—Prof. H. E. Armstrong, F.R.S.; Prof. J. O. Arnold, D.Met.; Prof. H. M. Howe, LL.D.; Prof. Orme Masson, F.R.S.; Prof. W. P. Wynne, F.R.S. *Secretaries.*—Dr. E. F. Armstrong (*Recorder*); Dr. T. M. Lowry; Dr. F. M. Perkin; W. E. S. Turner, M.Sc.

SUB-SECTION.—AGRICULTURE.

Chairman.—A. D. Hall, M.A., F.R.S. *Vice-Chairman.*—Major P. G. Craigie, C.B.; Prof. T. B. Wood. *Secretaries.*—Dr. E. J. Russell (*Recorder*); Dr. C. Crowther; J. Golding.

SECTION C.—GEOLOGY.

President.—Prof. A. P. Coleman, Ph.D., F.R.S. *Vice-Presidents.*—Prof. W. H. Hobbs; Prof. P. F. Kendall, M.Sc.; Prof. W. W. Watts, F.R.S.; Dr. A. Smith Woodward, F.R.S. *Secretaries.*—W. Lower Carter, M.A. (*Recorder*); Dr. A. R. Dwerryhouse; B. Hobson, M.Sc.; Prof. S. H. Reynolds, M.A.

SECTION D.—ZOOLOGY.

President.—Prof. G. C. Bourne, F.R.S. *Vice-Presidents.*—Prof. A. Denny, M.Sc.; Dr. H. F. Gadow, F.R.S.; Dr. A. E. Shipley, F.R.S. *Secretaries.*—Dr. H. W. Marett Tims (*Recorder*); Dr. J. H. Ashworth; L. Doncaster, M.A.; T. J. Evans, B.A.

SECTION E.—GEOGRAPHY.

President.—Prof. A. J. Herbertson, Ph.D. *Vice-Presidents.*—J. Bolton; G. G. Chisholm, M.A., B.Sc.; Colonel H. W. Feilden, C.B.; Colonel Sir D. A. Johnston, K.C.M.G., R.E.; J. Howard Reed. *Secretaries.*—Rev. W. J. Barton, B.A. (*Recorder*); Dr. R. N. Rudmose Brown; J. McFarlane, M.A.; E. A. Reeves.

SECTION F.—ECONOMIC SCIENCE AND STATISTICS.

President.—Sir H. Llewellyn Smith, K.C.B., F.S.S. *Vice-Presidents.*—Prof. E. Cannan, LL.D.; Prof. S. J. Chapman, M.A.; Prof. H. B. Lees Smith, M.A., M.P. *Secretaries.*—H. O. Meredith, M.A. (*Recorder*); C. R. Fay, M.A.; Dr. W. R. Scott; R. Wilson, B.A.

SECTION G.—ENGINEERING.

President.—Prof. W. E. Dalby, M.A. *Vice-Presidents.*—Dugald Clerk, F.R.S.; Sir R. A. Hadfield, F.R.S.; Charles Hawksley; Prof. W. Ripper, D.Eng.; Douglas Vickers; Sir W. H. White, K.C.B., F.R.S. *Secretaries.*—Prof. E. G. Coker (*Recorder*); F. Boulden, B.Sc.; A. A. Rowse, B.Sc.; H. E. Wimperis, M.A.

SECTION H.—ANTHROPOLOGY.

President.—W. Crooke, B.A. *Vice-Presidents.*—Prof. A. F. Dixon, Sc.D.; Miss A. C. Fletcher; Prof. J. L. Myres, M.A.; Dr. W. H. R. Rivers, F.R.S. *Secretaries.*—E. N. Fallaize, B.A. (*Recorder*); H. S. Kingsford, M.A.; Prof. C. J. Patten; Dr. F. C. Shrubsall.

SECTION I.—PHYSIOLOGY.

President.—Prof. A. B. Macallum, F.R.S. *Vice-Presidents.*—Prof. J. S. Macdonald; Prof. E. A. Schäfer, F.R.S.; Prof. C. S. Sherrington, F.R.S.; Prof. Wm. Stirling; Dr. A. D. Waller, F.R.S. *Secretaries.*—Dr. H. E. Roaf (*Recorder*); Dr. H. G. M. Henry; Keith Lucas, M.A.; Dr. J. Tait.

SECTION K.—BOTANY.

President.—Prof. J. W. H. Trail, F.R.S. *Vice-Presidents.*—Prof. F. O. Bower, F.R.S.; Prof. J. B. Farmer, F.R.S.; Lieut.-Col. D. Prain, C.I.E., F.R.S.; Dr. A. B. Rendle, F.R.S. *Secretaries.*—Prof. R. H. Yapp, M.A. (*Recorder*); B. H. Bentley, M.A.; R. P. Gregory, M.A.; Prof. D. T. Gwynne-Vaughan, M.A.

SECTION L.—EDUCATIONAL SCIENCE.

President.—Principal H. A. Miers, F.R.S. *Vice-Presidents.*—R. Blair, M.A.; Prof. J. A. Green, M.A; Prof. R. A. Gregory. *Secretaries*—J. L. Holland. B.A. (*Recorder*); A. J. Arnold, B.A.; W. D. Eggar, M.A.; Hugh Richardson, M.A.

CONFERENCE OF DELEGATES OF CORRESPONDING SOCIETIES.

Chairman.—Dr. Tempest Anderson. *Vice-Chairman*—Prof. P. F. Kendall. *Secretary.*—W. P. D. Stebbing.

COMMITTEE OF RECOMMENDATIONS.

The President and Vice-Presidents of the Association; the General Secretaries; the General Treasurer; the Trustees; the Presidents of the Association in former years; the Chairman of the Conference of Delegates; Prof. E. W. Hobson; Dr. C. Chree; J. E. Stead; Dr. E. F. Armstrong; Prof. A. P. Coleman; W. Lower Carter; Prof. G. C. Bourne; Dr. Marett Tims; Prof. A. J. Herbertson; Rev. W. J. Barton; Prof. S. J. Chapman; H. O. Meredith; Prof. W. E. Dalby; Prof. E. G. Coker; W. Crooke; E. N. Fallaize; Prof. A. B. Macallum; Dr. H. E. Roaf; Prof. J. W. H. Trail; Prof. R. H. Yapp; Principal H. A. Miers; J. L. Holland; and A. D. Hall.

RESEARCH COMMITTEES, ETC., APPOINTED BY THE GENERAL COMMITTEE AT THE SHEFFIELD MEETING: SEPTEMBER 1910.

1. *Receiving Grants of Money.*

Subject for Investigation, or Purpose	Members of Committee	Grants
SECTION A.—MATHEMATICS AND PHYSICS.		£ s. d.
Seismological Observations.	*Chairman.*—Professor H. H. Turner. *Secretary.*—Dr. J. Milne. Mr. C. V. Boys, Mr. Horace Darwin, Major L. Darwin, Dr. R. T. Glazebrook, Mr. M. H. Gray, Professors J. W. Judd, C. G. Knott, and R. Meldola, Mr. R. D. Oldham, Professor J. Perry, Mr. W. E. Plummer, Professor J. H. Poynting, Mr. Clement Reid, and Mr. Nelson Richardson.	60 0 0
To co-operate with the Committee of the Falmouth Observatory in their Magnetic Observations.	*Chairman.*—Sir W. H. Preece. *Secretary.*—Dr. W. N. Shaw. Professor W. G. Adams, Captain Creak, Mr. W. L. Fox, Dr. R. T. Glazebrook, Professor A. Schuster, Sir A. W. Rücker, and Dr. Charles Chree.	25 0 0
To aid the work of Establishing a Solar Observatory in Australia.	*Chairman.*—Sir David Gill. *Secretary.*—Dr. W. G. Duffield. Dr. W. J. S. Lockyer, Mr. F. McClean, and Professors A. Schuster and H. H. Turner.	50 0 0
Investigation of the Upper Atmosphere.	*Chairman.*—Dr. W. N. Shaw. *Secretary.*—Mr. E. Gold. Mr. D. Archibald, Mr. C. Vernon Boys, Mr. C. J. P. Cave, Mr. W. H. Dines, Dr. R. T. Glazebrook, Professor J. E. Petavel, Dr. A. Schuster, Dr. W. Watson, and Sir J. Larmor.	25 0 0
Grant to the International Commission on Physical and Chemical Constants.	—	30 0 0

1. *Receiving Grants of Money*—continued.

Subject for Investigation, or Purpose	Members of Committee	Grants
	SECTION B.—CHEMISTRY.	£ s. d.
The Study of Hydro-aromatic Substances.	*Chairman.*—Professor E. Divers. *Secretary.*—Professor A. W. Crossley. Professor W. H. Perkin, Dr. M. O. Forster, and Dr. Le Sueur.	20 0 0
Dynamic Isomerism.	*Chairman.*—Professor H. E Armstrong. *Secretary.*—Dr. T. M. Lowry. Professor Sydney Young, Dr. Desch, Dr. J. J. Dobbie, Dr. A. Lapworth, and Dr. M. O. Forster.	25 0 0
The Transformation of Aromatic Nitroamines and allied substances, and its relation to Substitution in Benzene Derivatives.	*Chairman.*—Professor F. S. Kipping. *Secretary.*—Professor K. J. P. Orton. Dr. S. Ruhemann, Dr. A. Lapworth, and Dr. J. T. Hewitt.	15 0 0
Electroanalysis.	*Chairman.*—Professor F. S. Kipping. *Secretary.*—Dr. F. M. Perkin. Dr. G. T. Beilby, Dr. T. M. Lowry, Professor W. J. Pope, and Dr. H. J. S. Sand.	15 0 0
The Influence of Carbon and other Elements on the Corrosion of Steel.	*Chairman.*—Professor J. O. Arnold. *Secretary.*—Mr. W. E. S. Turner. Professor W. P. Wynne, Professor A. McWilliam, Mr. C. Chappell, and Mr. F. Hodson.	15 0 0
	SECTION C.—GEOLOGY.	
To investigate the Erratic Blocks of the British Isles, and to take measures for their preservation.	*Chairman.*—Mr. R. H. Tiddeman. *Secretary.*—Dr. A. R. Dwerryhouse. Dr. T. G. Bonney, Mr. F. M. Burton, Mr. F. W. Harmer, Rev. S. N. Harrison, Dr. J. Horne, Mr. W. Lower Carter, Professor W. J. Sollas, and Messrs. Wm. Hill, J. W. Stather, and J. H. Milton.	10 0 0
To enable Mr. E. Greenly to complete his Researches on the Composition and Origin of the Crystalline Rocks of Anglesey.	*Chairman.*—Mr. A. Harker. *Secretary.*—Mr. E. Greenly. Dr. J. Horne, Dr. C. A. Matley, and Professor K. J. P. Orton.	2 0 0
To excavate Critical Sections in the Palæozoic Rocks of Wales and the West of England.	*Chairman.*—Professor C. Lapworth. *Secretary.*—Mr. W. G. Fearnsides. Dr. Herbert Lapworth, Dr. J. E. Marr, Professor W. W. Watts, and Mr. G. J. Williams.	10 0 0
To investigate the Microscopical and Chemical Composition of Charnwood Rocks.	*Chairman.* — Professor W. W. Watts. *Secretary.*—Dr. T. T. Groom. Dr. F. W. Bennett and Dr. Stracey.	2 0 0

1. *Receiving Grants of Money*—continued.

Subject for Investigation, or Purpose	Members of Committee	Grants
		£ s. d.
The Investigation of the Igneous and Associated Rocks of Glensaul and Lough Nafooey Areas, Co. Galway.	*Chairman.*—Professor W. W. Watts. *Secretary.*—Professor S. H. Reynolds. Messrs. H. B. Maufe and C. I. Gardiner.	15 0 0
To enable Mr. C. Forster Cooper to examine the Mammalian Fauna in the Miocene deposits of the Bugti Hills, Baluchistan.	*Chairman.*—Professor G. C. Bourne. *Secretary.*—Mr. C. Forster Cooper. Drs. A. Smith Woodward, A. E. Shipley, C. W. Andrews, and H. F. Gadow and Professor J. Stanley Gardiner.	45 0 0

Section D.—ZOOLOGY.

Subject for Investigation, or Purpose	Members of Committee	Grants
To aid competent Investigators selected by the Committee to carry on definite pieces of work at the Zoological Station at Naples.	*Chairman.*—Professor S. J. Hickson. *Secretary.*—Mr. E. S. Goodrich. Sir E. Ray Lankester, Professor A. Sedgwick, Professor W. C. McIntosh, Dr. S. F. Harmer, Mr. G. P. Bidder, Dr. W. B. Hardy, and Professor A. D. Waller.	75 0 0
Compilation of an Index Generum et Specierum Animalium.	*Chairman.*—Dr. H. Woodward. *Secretary.*—Dr. F. A. Bather. Dr. P. L. Sclater, Rev. T. R. R. Stebbing, Dr. W. E. Hoyle, the Hon. Walter Rothschild, and Lord Walsingham.	75 0 0
To investigate the Feeding Habits of British Birds by a study of the contents of the crops and gizzards of both adults and nestlings, and by collation of observational evidence, with the object of obtaining precise knowledge as to the economic status of many of our commoner birds affecting rural science.	*Chairman.*—Dr. A. E. Shipley. *Secretary.*—Mr. H. S. Leigh. Messrs. J. N. Halbert, Robert Newstead, Clement Reid, A. G. L. Rogers, and F. V. Theobald, Professor F. E. Weiss, Dr. C. Gordon Hewitt, and Professors S. J. Hickson, F. W. Gamble, G. H. Carpenter, and J. Arthur Thomson.	5 0 0
To investigate the Biological Problems incidental to the Belmullet Whaling Station.	*Chairman.*—Dr. A. E. Shipley. *Secretary.*—Professor J. Stanley Gardiner. Professor W. A. Herdman, Rev. W. Spotswood Green, Mr. E. S. Goodrich, Dr. H. W. Marett Tims, and Mr. R. M. Barrington.	30 0 0
To enable Mr. C. Forster Cooper to examine the Mammalian Fauna in the Miocene deposits of the Bugti Hills, Baluchistan.	*Chairman.*—Professor G. C. Bourne. *Secretary.*—Mr. C. Forster Cooper. Drs. A. Smith Woodward, A. E. Shipley, C. W. Andrews, and H. F. Gadow and Professor J. Stanley Gardiner.	30 0 0

1. *Receiving Grants of Money*—continued.

Subject for Investigation, or Purpose	Members of Committee	Grants
Section E.—GEOGRAPHY.		£ s. d.
To complete the map of Prince Charles Foreland, Spitzbergen, based on the surveys of 1906, 1907, and 1909, made by Dr. W. S. Bruce.	*Chairman.*—Mr. G. G. Chisholm. *Secretary.*—Dr. R. N. Rudmose Brown. Sir Duncan Johnston and Mr. E. A. Reeves.	30 0 0
Upon a new series of equal area maps, to measure areas of vertical relief, vegetation, and rainfall; to calculate the mean levels of the sphere, the continents and the oceans, and the total mean annual rainfall over the lands.	*Chairman.*—Professor A. J. Herbertson. *Secretary.*—Mr. E. A. Reeves. Dr. H. R. Mill, Mr. G. G. Chisholm, and Colonel C. F. Close.	20 0 0
Section F.—ECONOMIC SCIENCE AND STATISTICS.		
The Amount and Distribution of Income (other than Wages) below the Income-tax exemption limit in the United Kingdom.	*Chairman.*—Professor E. Cannan. *Secretary.*—Professor A. L. Bowley. Dr. W. R. Scott, and Professors F. Y. Edgeworth and H. B. Lees Smith.	5 0 0
Section G.—ENGINEERING.		
The Investigation of Gaseous Explosions, with special reference to Temperature.	*Chairman.*—Sir W. H. Preece. *Secretaries.*—Mr. Dugald Clerk and Professor B. Hopkinson. Professors W. A. Bone, F. W. Burstall, H. L. Callendar, E. G. Coker, W. E. Dalby, and H. B. Dixon, Drs. R. T. Glazebrook and J. A. Harker, Colonel H. C. L. Holden, Professor J. E. Petavel, Captain H. Riall Sankey, Professor A. Smithells, Professor W. Watson, Mr. D. L. Chapman, and Mr. H. E. Wimperis.	90 0 0
Section H.—ANTHROPOLOGY.		
To investigate the Lake Villages in the neighbourhood of Glastonbury in connection with a Committee of the Somerset Archæological and Natural History Society.	*Chairman.*—Dr. R. Munro. *Secretary.*—Professor W. Boyd Dawkins. Professor W. Ridgeway, Dr. Arthur J. Evans, Dr. C. H. Read, Mr. H. Balfour, and Mr. A. Bulleid.	5 0 0
To co-operate with Local Committees in Excavations on Roman Sites in Britain.	*Chairman.*—Professor J. L. Myres. *Secretary.*—Professor R. C. Bosanquet. Dr. T. Ashby and Professor W. Ridgeway.	10 0 0

1. *Receiving Grants of Money*—continued.

Subject for Investigation, or Purpose	Members of Committee	Grants
		£ s. d.
To conduct Explorations with the object of ascertaining the Age of Stone Circles.	*Chairman.*—Dr. C. H. Read. *Secretary.*—Mr. H. Balfour. Lord Avebury, Professor W. Ridgeway, Dr. J. G. Garson, Dr. A. J. Evans, Dr. R. Munro, Professor Boyd Dawkins, and Mr. A. L. Lewis.	30 0 0
To prepare a New Edition of Notes and Queries in Anthropology.	*Chairman.*—Dr. C. H. Read. *Secretary.*—Professor J. L. Myres. Mr. E. N. Fallaize, Dr. A. C. Haddon, Mr. T. A. Joyce, and Drs. C. S. Myers, W. H. R. Rivers, C. G. Seligmann, and F. C. Shrubsall.	40 0 0
To investigate and ascertain the Distribution of Artificial Islands in the lochs of the Highlands of Scotland.	*Chairman.*—Dr. R. Munro. *Secretary.*—Professor J. L. Myres. Professors T. H. Bryce and W. Boyd Dawkins.	10 0 0
SECTION I.—PHYSIOLOGY.		
The Ductless Glands.	*Chairman.*—Professor Schäfer. *Secretary.*—Professor Swale Vincent. Professor A. B. Macallum, Dr. L. E. Shore, and Mrs. W. H. Thompson.	40 0 0
Body Metabolism in Cancer.	*Chairman.*—Professor C. S. Sherrington. *Secretary.*—Dr. S. M. Copeman.	6 13 0
To aid competent Investigators selected by the Committee to carry on definite pieces of work at the Zoological Station at Naples.	*Chairman.*—Professor S. J. Hickson. *Secretary.*—Mr. E. S. Goodrich. Sir E. Ray Lankester, Professor A. Sedgwick, Professor W. C. McIntosh, Dr. S. F. Harmer, Mr. G. P. Bidder, Dr. W. B. Hardy, and Professor A. D. Waller.	25 0 0
To acquire further knowledge, Clinical and Experimental, concerning Anæsthetics—especially Chloroform, Ether, and Alcohol—with special reference to Deaths by or during Anæsthesia, and their possible diminution.	*Chairman.*—Dr. A. D. Waller. *Secretary.*—Dr. F. W. Hewitt. Dr. Blumfeld, Mr. J. A. Gardner, and Dr. G. A. Buckmaster.	20 0 0
Mental and Muscular Fatigue.	*Chairman.*—Professor C. S. Sherrington. *Secretary.*—Dr. W. MacDougall. Professor J. S. MacDonald, Mr. H. Sackville Lawson, and Mr. G. Chapman.	25 0 0

1. *Receiving Grants of Money*—continued.

Subject for Investigation, or Purpose	Members of Committee	Grants £ s. d.
Electromotive Phenomena in Plants.	*Chairman.*—Dr. A. D. Waller. *Secretary.*—Mrs. Waller. Professors F. Gotch, J. B. Farmer, and Veley, and Dr. F. O'B. Ellison.	10 0 0
The Dissociation of Oxy-Hæmoglobin at High Altitudes.	*Chairman.*—Professor E. H. Starling. *Secretary.*—Dr. J. Barcroft. Dr. W. B. Hardy.	25 0 0
SECTION K.—BOTANY.		
The Structure of Fossil Plants.	*Chairman.*—Dr. D. H. Scott. *Secretary.*—Professor F.W. Oliver. Mr. E. Newell Arber and Professors A. C. Seward and F. E Weiss.	15 0 0
The Experimental Study of Heredity.	*Chairman.*—Mr. Francis Darwin. *Secretary.*—Mr. A. G. Tansley. Professors Bateson and Keeble.	45 0 0
A Botanical, Zoological, and Geological Survey of Clare Island.	*Chairman.*—Professor T. Johnson. *Secretary.*—Mr. R. Lloyd Praeger. Professor Grenville Cole, Dr. Scharff, and Mr. A. G. Tansley.	20 0 0
To carry out the scheme for the Registration of Negatives of Botanical Photographs.	*Chairman.*—Professor F.W. Oliver. *Secretary.*—Professor F. E. Weiss. Dr. W. G. Smith, Mr. A. G. Tansley, Dr. T. W. Woodhead, and Professor R. H. Yapp.	10 0 0
SECTION L.—EDUCATIONAL SCIENCE.		
To inquire into and report upon the methods and results of research into the Mental and Physical Factors involved in Education.	*Chairman.*—Professor J. J. Findlay. *Secretary.*—Professor J. A. Green. Professors J. Adams and E. P. Culverwell, Mr. G. F. Daniell, Miss B. Foxley, Mr. J. Gray, Professor R. A. Gregory, Dr. C. W. Kimmins, Professor W. MacDougall, Dr. T. P. Nunn, Dr. W. H. R. Rivers, Dr. C. Spearman, Miss L. Edna Walter, and Dr. F. Warner.	10 0 0
CORRESPONDING SOCIETIES.		
Corresponding Societies Committee for the preparation of their Report.	*Chairman.*—Mr. W. Whitaker. *Secretary.*—Mr. W. P. D. Stebbing. Rev. J. O. Bevan, Sir Edward Brabrook, Dr. J. G. Garson, Principal E. H. Griffiths, Dr. A. C. Haddon, Mr. T. V. Holmes, Mr. J. Hopkinson, Mr. A. L. Lewis, Mr. F. W. Rudler, Rev. T. R. R. Stebbing, and the President and General Officers of the Association.	20 0 0

2. *Not receiving Grants of Money.*

Subject for Investigation, or Purpose	Members of Committee
SECTION A.—MATHEMATICS AND PHYSICS.	
Making Experiments for improving the Construction of Practical Standards for use in Electrical Measurements.	*Chairman.*—Lord Rayleigh. *Secretary.*—Dr. R. T. Glazebrook. Professors J. Perry and W. G. Adams, Dr. G. Carey Foster, Sir Oliver Lodge, Dr. A. Muirhead, Sir W. H. Preece, Professor A. Schuster, Dr. J. A. Fleming, Professor Sir J. J. Thomson, Dr. W. N. Shaw, Dr. J. T. Bottomley, Rev. T. C. Fitzpatrick, Dr. G. Johnstone Stoney, Professor S. P. Thompson, Mr. J. Rennie, Principal E. H. Griffiths, Sir Arthur Rücker, Professor H. L. Callendar, and Messrs. G. Matthey, T. Mather, and F. E. Smith.
The further Tabulation of Bessel and other Functions.	*Chairman.*—Professor M. J. M. Hill. *Secretary.*—Mr. J. W. Nicholson. Professor Alfred Lodge, Dr. L. N. G. Filon, and Sir G. Greenhill.
To consider the advisability of drawing up a Report on Non-Euclidean Geometry, and to draw up the Report if it should seem advisable.	*Chairman.*—Dr. H. F. Baker. *Secretary.*—Mr. D. M. Y. Sommerville. Professor Chrystal and Mr. A. N. Whitehead.
SECTION B.—CHEMISTRY.	
The Study of Isomorphous Sulphonic Derivatives of Benzene.	*Chairman.*—Professor H. A. Miers. *Secretary.*—Professor H. E. Armstrong. Professors W. P. Wynne and W. J. Pope.
SECTION C.—GEOLOGY.	
To determine the precise Significance of Topographical and Geological Terms used locally in South Africa.	*Chairman.*—Mr. G. W. Lamplugh. *Secretary.*—Dr. F. H. Hatch. Dr. G. Corstorphine and Messrs. A. Du Toit, A. P. Hall, G. Kynaston, F. P. Mennell, and A. W. Rogers.
To investigate the Fossil Flora and Fauna of the Midland Coalfields.	*Chairman.*—Dr. L. Moysey. *Secretary.*—Mr. B. Hobson Dr. Wheelton Hind, Mr. H. Bolton, and Dr. A. R. Dwerryhouse.
The Collection, Preservation, and Systematic Registration of Photographs of Geological Interest.	*Chairman.*—Professor J. Geikie. *Secretaries.*—Professors W. W. Watts and S. H. Reynolds. Dr. T. Anderson, Mr. G. Bingley, Dr. T. G. Bonney, Mr. C. V. Crook, Professor E. J. Garwood, and Messrs. W. Gray, R. Kidston, A. S. Reid, J. J. H. Teall, R. Welch, W. Whitaker, and H. B. Woodward.

2. *Not receiving Grants of Money*—continued.

Subject for Investigation, or Purpose	Members of Committee
To consider the preparation of a List of Characteristic Fossils.	*Chairman.*—Professor P. F. Kendall. *Secretary.*—Mr. W. Lower Carter. Professor W. S. Boulton, Professor G. Cole, Dr. A. R. Dwerryhouse, Professors J. W. Gregory, Sir T. H. Holland, and S. H. Reynolds, Miss M. C. Stopes, Mr. Cosmo Johns, Dr. J. E. Marr, Dr. A. Vaughan, Professor W. W. Watts, and Dr. A. Smith Woodward.

Section D.—ZOOLOGY.

To continue the Investigation of the Zoology of the Sandwich Islands, with power to co-operate with the Committee appointed for the purpose by the Royal Society, and to avail themselves of such assistance in their investigations as may be offered by the Hawaiian Government or the Trustees of the Museum at Honolulu. The Committee to have power to dispose of specimens where advisable.	*Chairman.*—Dr. F. Du Cane Godman. *Secretary.*—Dr. David Sharp. Professor S. J. Hickson, Dr. P. L. Sclater, and Mr. Edgar A. Smith.
To summon meetings in London or elsewhere for the consideration of matters affecting the interests of Zoology or Zoologists, and to obtain by correspondence the opinion of Zoologists on matters of a similar kind, with power to raise by subscription from each Zoologist a sum of money for defraying current expenses of the Organisation.	*Chairman.*—Sir E. Ray Lankester. *Secretary.*—Professor S. J. Hickson. Professors G. C. Bourne, J. Cossar Ewart, M. Hartog, W. A. Herdman, and J. Graham Kerr, Mr. O. H. Latter, Professor Minchin, Dr. P. C. Mitchell, Professors E. B. Poulton and A. Sedgwick, and Dr. A. E. Shipley.
To nominate competent naturalists to perform definite pieces of work at the Marine Laboratory, Plymouth.	*Chairman* and *Secretary.*—Professor A. Dendy. Sir E. Ray Lankester, Professor A. Sedgwick, Professor Sydney H. Vines, and Mr. E. S. Goodrich.
To enable Mr. Laurie to conduct Experiments in Inheritance.	*Chairman.*—Professor W. A. Herdman. *Secretary.*—Mr. Douglas Laurie. Professor R. C. Punnett and Dr. H. W. Marett Tims.
To formulate a Definite System on which Collectors should record their captures.	*Chairman.*—Professor J. W. H. Trail. *Secretary*—Mr. F. Balfour Browne. Dr. Scharff, Professor G. H. Carpenter, Professor E. B. Poulton, and Mr. A. G. Tansley.

Section H.—ANTHROPOLOGY.

The Collection, Preservation and Systematic Registration of Photographs of Anthropological Interest.	*Chairman.*—Dr. C. H. Read. *Secretary.*—Mr. H. S. Kingsford. Dr. G. A. Auden, Mr. E. Heawood, and Professor J. L. Myres.

2. *Not receiving Grants of Money*—continued.

Subject for Investigation, or Purpose	Members of Committee
To organise Anthropometric Investigation in the British Isles.	*Chairman.*—Professor A. Thomson. *Secretary.*—Mr. J. Gray. Dr. F. C. Shrubsall.
To excavate Neolithic Sites in Northern Greece.	*Chairman.*—Professor W. Ridgeway. *Secretary.*—Professor J. L. Myres. Mr. J. P. Droop and Mr. D. G. Hogarth.
To conduct Archæological and Ethnological Researches in Crete.	*Chairman.*—Mr. D. G. Hogarth. *Secretary.*—Professor J. L. Myres. Professor R. C. Bosanquet, Dr. W. L. H. Duckworth, Dr. A. J. Evans, Professor A. Macalister, Professor W. Ridgeway, and Dr. F. C. Shrubsall.
To advise on the best method of publishing a collection of Hausa Folklore with translations and grammatical notes.	*Chairman.*—Mr. E. S. Hartland. *Secretary.*—Dr. A. C. Haddon. Professor J. L. Myres.
To report on the present state of knowledge of the Prehistoric Civilisation of the Western Mediterranean with a view to future research.	*Chairman.*—Professor W. Ridgeway. *Secretary.*—Professor J. L. Myres. Dr. T. Ashby, Dr. W. L. H. Duckworth, Mr. D. G. Hogarth, and Dr. A. J. Evans.
To co-operate with a local Committee in the excavation of a prehistoric site at Bishop's Stortford.	*Chairman.*—Professor W. Ridgeway. *Secretary.*—Rev. Dr. A. Irving. Dr. A. C. Haddon and Dr. H. W. Marett Tims.

SECTION I.—PHYSIOLOGY.

The Effect of Climate upon Health and Disease.	*Chairman.*—Sir T. Lauder Brunton. *Secretaries.*—Mr. J. Barcroft and Lieut.-Col. Simpson. Colonel Sir D. Bruce, Dr. S. G. Campbell, Sir Kendal Franks, Professor J. G. McKendrick, Sir A. Mitchell, Dr. Porter, Dr. J. L. Todd, Professor Sims Woodhead, and the Heads of the Tropical Schools of Liverpool, London, and Edinburgh.
Tissue Metabolism, for the Investigation of the Metabolism of Special Organs.	*Chairman.*—Professor E. H. Starling. *Secretary.*—Professor T. G. Brodie. Dr. J. S. Haldane.

SECTION K.—BOTANY.

To consider the promotion of the Study of the Plant Life of the British Islands, and the preparation of the materials for a National Flora.	*Chairman.*—Professor J. W. H. Trail. *Secretary.*—Professor R. H. Yapp. Colonel D. Prain, Professor I. Bayley Balfour, Mr. R. Lloyd Praeger, Mr. A. B. Rendle, Dr. W. G. Smith, and Mr. A. G. Tansley.

2. *Not receiving Grants of Money*—continued.

Subject for Investigation, or Purpose	Members of Committee
SECTION L.—EDUCATIONAL SCIENCE.	
To take notice of, and report upon changes in, Regulations—whether Legislative, Administrative, or made by Local Authorities — affecting Secondary Education.	*Chairman.*—Sir Philip Magnus. *Secretary.*—Professor H. E. Armstrong. Mr. S. H. Butcher, Sir Henry Craik, Principal Griffiths, Sir Horace Plunkett, and Professor M. E. Sadler.
To inquire into the Curricula and Educational Organisation of Industrial and Poor Law Schools with special reference to Day Industrial Schools.	*Chairman.*—Mr. W. D. Eggar. *Secretary.*—Mrs. W. N. Shaw. Mr. J. L. Holland, Dr. C. W. Kimmins, and Mr. J. G. Legge.
To report upon the Course of Experimental, Observational, and Practical Studies most suitable for Elementary Schools.	*Chairman.*—Sir Philip Magnus. *Secretary.*—Mr. W. M. Heller. Sir W. de W. Abney, Mr. R. H. Adie, Professor H. E. Armstrong, Miss L. J. Clarke, Miss A. J. Cooper, Mr. George Fletcher, Professor R. A. Gregory, Principal Griffiths, Mr. A. D. Hall, Dr. A. J. Herbertson, Dr. C. W. Kimmins, Professor L. C. Miall, Professor J. Perry, Mrs. W. N. Shaw, Professor A. Smithells, Dr. Lloyd Snape, Sir H. R. Reichel, Mr. H. Richardson, and Professor W. W. Watts.
To inquire into and report upon the overlapping between Secondary Education and that of Universities and other places of Higher Education.	*Chairman.*—Principal Miers. *Secretary.*—Professor R. A. Gregory. Messrs. D. Berridge and C. H. Bothamley, Miss L. J. Clarke, Miss A. J. Cooper, Miss B. Foxley, Principal E. H. Griffiths, Mr. H. Bompas Smith, and Professor Smithells.

Communications ordered to be printed in extenso.

Report on Solubility, by Dr. J. V. Eyre.
Discussion on Dr. Bone's Report on Combustion (to follow the Report).
The Present State of the Theory of Integral Equations, by Mr. H. Bateman.
Bibliography of Papers on Photo-electric Fatigue, by Dr. H. S. Allen.

Resolutions referred to the Council for consideration, and, if desirable, for action.

From the General Committee.

That the Recommendation to form a permanent Sub-section of Agriculture, contained in paragraph V. of the Report of the Council, be referred back to the Council.

From Section D.

That Section D reaffirms its resolution of September 3, 1908, and urges the Nomenclature Commission of the International Congress of Zoology to draw up an official list of generic names, with as little delay as possible, which shall not on nomenclatorial grounds be changed unless with the sanction of the Commission.

From Section E.

That the Council be requested to bring under the notice of His Majesty's Government the high prices that recently have been fixed for many Geological Survey Maps, which tend to keep the valuable information given by these maps from being circulated as freely as it ought to be, the sale now being practically limited to persons of some means.

From Section H.

To recommend the Council to bring to the notice of His Majesty's Secretary of State for the Colonies the defects of the present administration of antiquities in Cyprus and to urge the necessity of prompt and efficient measures under a trained official directly responsible to the Island Government to prevent the destruction and spoliation of ancient remains in the island.

From Section I.

The Committee of Section I begs to call attention to the fact that during the past year resolutions have been adopted by the General Medical Council in support of early legislation to secure better regulation of the administration of general anæsthetics, and that the recent report of a Departmental Committee of the Home Office has laid special stress upon the need of careful clinical observation controlled by physiological experiments.

The Committee asks the Association to support such legislation and inquiry.

Recommendations referred to the Council for consideration, and, if desirable, for action.

That the following Committees be authorised to receive contributions from sources other than the Association:—

'To conduct Explorations with a view to ascertaining the Age of Stone Circles.' (Section H.)

'To aid investigators . . . to carry on . . . work at the Zoological Station at Naples.' (Section D.)

Synopsis of Grants of Money appropriated for Scientific Purposes by the General Committee at the Sheffield Meeting, September 1910. *The Names of Members entitled to call on the General Treasurer for the Grants are prefixed.*

	£	s.	d.
Mathematical and Physical Science.			
*Turner, Professor H. H.—Seismological Observations	60	0	0
*Preece, Sir W. H.—Magnetic Observations at Falmouth ...	25	0	0
*Gill, Sir David—Establishing a Solar Observatory in Australia	50	0	0
*Shaw, Dr. W. N.—Investigation of the Upper Atmosphere	25	0	0
—— Grant to the International Commission on Physical and Chemical Constants	30	0	0
Chemistry.			
*Divers, Professor E.—Study of Hydro-aromatic Substances	20	0	0
*Armstrong, Professor H. E.—Dynamic Isomerism	25	0	0
*Kipping, Professor F. S.—Transformation of Aromatic Nitro-amines	15	0	0
*Kipping, Professor F. S.—Electroanalysis	15	0	0
Arnold, Professor J. O.—Influence of Carbon, &c., on Corrosion of Steel	15	0	0
Geology.			
*Tiddeman, R. H.—Erratic Blocks	10	0	0
*Harker, A.—Crystalline Rocks of Anglesey	2	0	0
*Lapworth, Professor C.—Palæozoic Rocks of Wales and the West of England	10	0	0
*Watts, Professor W. W.—Composition of Charnwood Rocks	2	0	0
*Watts, Professor W. W.—Igneous and Associated Rocks of Glensaul, &c.	15	0	0
Bourne, Professor G. C.—Mammalian Fauna in Miocene Deposits, Bugti Hills, Baluchistan	45	0	0
Zoology.			
*Hickson, Professor S. J.—Table at the Zoological Station at Naples	75	0	0
*Woodward, Dr. H.—Index Animalium	75	0	0
*Shipley, A. E.—Feeding Habits of British Birds..............	5	0	0
Shipley, Dr. A. E.—Belmullet Whaling Station	30	0	0
Bourne, Professor G. C.—Mammalian Fauna in Miocene Deposits, Bugti Hills, Baluchistan	30	0	0
Carried forward	£579	0	0

* Reappointed.

	£	s.	d.
Brought forward	579	0	0

Geography.

Chisholm, G. G.—Map of Prince Charles Foreland	30	0	0
Herbertson, Professor A. J.—Equal Area Maps	20	0	0

Economic Science and Statistics.

*Cannan, Professor E.—Amount and Distribution of Income below the Income-tax Exemption Limit	5	0	0

Engineering.

*Preece, Sir W. H.—Gaseous Explosions	90	0	0

Anthropology.

*Munro, Dr. R.—Lake Villages in the neighbourhood of Glastonbury	5	0	0
*Myres, Professor J. L.—Excavations on Roman Sites in Britain	10	0	0
*Read, Dr. C. H.—Age of Stone Circles	30	0	0
*Read, Dr. C. H.—Anthropological Notes and Queries	40	0	0
Monro, Dr. R.—Artificial Islands in Highland Lochs	10	0	0

Physiology.

*Schäfer, Professor E. A.—The Ductless Glands	40	0	0
*Sherrington, Professor C. S.—Body Metabolism in Cancer...	6	13	0
*Hickson, Professor S. J.—Table at the Zoological Station at Naples	25	0	0
*Waller, Dr. A. D.—Anæsthetics	20	0	0
*Sherrington, Professor C. S.—Mental and Muscular Fatigue	25	0	0
*Waller, Dr. A. D.—Electromotive Phenomena in Plants ...	10	0	0
*Starling, Professor E. H.—Dissociation of Oxy-Hæmoglobin	25	0	0

Botany.

*Scott, Dr. D. H.—Structure of Fossil Plants	15	0	0
*Darwin, Dr. F.—Experimental Study of Heredity	45	0	0
*Johnson, Professor T.—Survey of Clare Island	20	0	0
*Oliver, Professor F. W.—Registration of Botanical Photographs	10	0	0
Carried forward	£1060	13	0

* Reappointed.

	£	s.	d.
Brought forward	1060	13	0

Education.

*Findlay, Professor J. J.—Mental and Physical Factors involved in Education	10	0	0

Corresponding Societies Committee.

*Whitaker, W.—For Preparation of Report	20	0	0
Total	£1090	13	0

* Reappointed.

Annual Meetings, 1911 *and* 1912.

The Annual Meeting of the Association in 1911 will be held at Portsmouth, commencing August 30; in 1912, at Dundee.

PRESIDENT'S ADDRESS.

1910.

ADDRESS

BY

THE REV. PROFESSOR T. G. BONNEY, Sc.D., LL.D., F.R.S.,

PRESIDENT.

THIRTY-ONE years have passed since the British Association met in Sheffield, and the interval has been marked by exceptional progress. A town has become a city, the head of its municipality a Lord Mayor; its area has been enlarged by more than one-fifth; its population has increased from about 280,000 to 479,000. Communication has been facilitated by the construction of nearly thirty-eight miles of electric tramways for home service and of new railways, including alternative routes to Manchester and London. The supplies of electricity, gas, and water have more than kept pace with the wants of the city. The first was just being attempted in 1879; the second has now twenty-three times as many consumers as in those days; the story[1] of the third has been told by one who knows it well, so that it is enough for me to say your water-supply cannot be surpassed for quantity and quality by any in the kingdom. Nor has Sheffield fallen behind other cities in its public buildings. In 1897 your handsome Town Hall was opened by the late Queen Victoria; the new Post Office, appropriately built and adorned with material from almost local sources, was inaugurated less than two months ago. The Mappin Art Gallery commemorates the munificence of those whose name it bears, and fosters that love of the beautiful which Ruskin sought to awaken by his liberal gifts. Last, but not least, Sheffield has shown that it could not rest satisfied till its citizens could ascend from their own doors to the highest rung of the educational ladder. Firth College, named after its bountiful founder, was born in the year of our last visit; in 1897 it received a charter as the University College of Sheffield, and in the spring of 1905 was created a University, shortly after which its fine new buildings were

[1] *History and Description of Sheffield Water Works.* W. Terrey, 1908.

opened by the late King; and last year its Library, the generous gift of Dr. Edgar Allen, was inaugurated by his successor, when Prince of Wales. I must not now dwell on the great work which awaits this and other new universities. It is for them to prove that, so far from abstract thought being antagonistic to practical work, or scientific research to the labour of the factory or foundry, the one and the other can harmoniously co-operate in the advance of knowledge and the progress of civilisation.

You often permit your President on these occasions to speak of a subject in which he takes a special interest, and I prefer thus trespassing on your kindness to attempting a general review of recent progress in science. I do not however propose, as you might naturally expect, to discuss some branch of petrology; though for this no place could be more appropriate than Sheffield, since it was the birthplace and the lifelong home of Henry Clifton Sorby, who may truly be called the father of that science. This title he won when, a little more than sixty years ago, he began to study the structure and mineral composition of rocks by examining thin sections of them under the microscope.[1] A rare combination of a singularly versatile and active intellect with accurate thought and sound judgment, shrewd in nature, as became a Yorkshireman, yet gentle, kindly, and unselfish, he was one whom his friends loved and of whom this city may well be proud. Sorby's name will be kept alive among you by the Professorship of Geology which he has endowed in your University; but, as the funds will not be available for some time, and as that science is so intimately connected with metallurgy, coal-mining, and engineering, I venture to express a hope that some of your wealthier citizens will provide for the temporary deficiency, and thus worthily commemorate one so distinguished.

But to return. I have not selected petrology as my subject, partly because I think that the great attention which its more minute details have of late received has tended to limit rather than to broaden our views, while for a survey of our present position it is enough to refer to the suggestive and comprehensive volume published last year by Mr. A. Harker;[2] partly, also, because the discussion of any branch of petrology would involve so many technicalities that I fear it would be found tedious by a large majority of my audience. So I have preferred to discuss some questions relating to the effects of ice which had engaged my attention a dozen years before I attempted the study of rock slices. As much of my petrological work has been connected with mountain

[1] His subsequent investigations into the microscopic structure of steel and other alloys of iron, in the manufacture of which your city holds a foremost place, have been extended by Mr. J. E. Stead and others, and they, besides being of great value to industrial progress, have thrown important sidelights on more than one dark place in petrology.

[2] *The Natural History of Igneous Rocks* (1909).

districts, it has been possible for me to carry on the latter without neglecting the former, and my study of ice-work gradually led me from the highlands into the lowlands.[1] I purpose, then, to ask your attention this evening to some aspects of the glacial history of Western Europe.

At no very distant geological epoch the climate in the northern part of the earth was much colder than it is at present. So it was also in the southern; but whether the two were contemporaneous is less certain. Still more doubtful are the extent and the work of the ice which was a consequence, and the origin of certain deposits on some northern lowlands, including those of our own islands: namely, whether they are the direct leavings of glaciers or were laid down beneath the sea by floating shore-ice and bergs. Much light will be thrown on this complex problem by endeavouring to ascertain what snow and ice have done in some region which, during the Glacial Epoch, was never submerged, and none better can be found for this purpose than the European Alps.

At the present day one school of geologists, which of late years has rapidly increased in number, claims for glaciers a very large share in the sculpture of that chain, asserting that they have not only scooped out the marginal lakes, as Sir A. Ramsay maintained full half a century ago, but have also quarried lofty cliffs, excavated great cirques, and deepened parts of the larger Alpine valleys by something like two thousand feet. The other school, while admitting that a glacier, in special circumstances, may hollow out a tarn or small lake and modify the features of rock scenery, declares that its action is abrasive rather than erosive, and that the sculpture of ridges, crags, and valleys was mainly accomplished in pre-glacial times by running water and the ordinary atmospheric agencies.

In all controversies, as time goes on, hypotheses are apt to masquerade as facts, so that I shall endeavour this evening to disentangle the two, and call attention to those which may be safely used in drawing a conclusion.

In certain mountain regions, especially those where strong limestones, granites, and other massive rocks are dominant, the valleys are often trench-like, with precipitous sides, having cirques or corries at their heads, and with rather wide and gently sloping floors, which occasionally descend in steps, the distance between these increasing with that from the watershed. Glaciers have unquestionably occupied many of these valleys, but of late years they have been supposed to have taken a large share in excavating them. In order to appreciate their action we must imagine the glens to be filled up and the district restored to its former condition of a more or less undulating upland. As the mean

[1] May I add that hereafter a statement of facts without mention of an authority means that I am speaking from personal knowledge?

temperature [1] declined snow would begin to accumulate in inequalities on the upper slopes. This, by melting and freezing, would soften and corrode the underlying material, which would then be removed by rain and wind, gravitation and avalanche. In course of time the hollow thus formed would assume more and more the outlines of a corrie or a cirque by eating into the hillside. With an increasing diameter it would be occupied, as the temperature fell, first by a permanent snowfield, then by the *névé* of a glacier. Another process now becomes important, that called 'sapping.' While ordinary glacier-scour tends, as we are told, to produce 'sweeping curves and eventually a graded slope,' 'sapping' produces 'benches and cliffs, its action being horizontal and backwards,' and often dominant over scour. The author of this hypothesis [2] convinced himself of its truth in the Sierra Nevada by descending a *bergschrund* 150 feet in depth, which opened out, as is so common, beneath the walls of a cirque. Beginning in the *névé*, it ultimately reached the cliff, so that for the last thirty feet the bold investigator found rock on the one hand and ice on the other. The former was traversed by fracture planes, and was in all stages of displacement and dislodgment; some blocks having fallen to the bottom, others bridging the narrow chasm, and others frozen into the *névé*. Clear ice had formed in the fissures of the cliff; it hung down in great stalactites; it had accumulated in stalagmitic masses on the floor. Beneath the *névé* the temperature would be uniform, so its action would be protective, except where it set up another kind of erosion, presently to be noticed; but in the chasm, we are informed, there would be, at any rate for a considerable part of the year, a daily alternation of freezing and thawing. Thus the cliff would be rapidly undermined and be carried back into the mountain slope, so that before long the glacier would nestle in a shelter of its own making. Further down the valley the moving ice would become more effective than sub-glacial streams in deepening its bed; but since the *névé*-flow is almost imperceptible near the head, another agency must be invoked, that of 'plucking.' The ice grips, like a forceps, any loose or projecting fragment in its rocky bed, wrenches that from its place, and carries it away. The extraction of one tooth weakens the hold of its neighbours, and thus the glen is deepened by 'plucking,' while it is carried back by 'sapping.' Streams from melting snows on the slopes above the amphitheatre might have been expected to co-operate vigorously in making it, but of them little account seems to be taken, and we are even told that in some cases the winds probably prevented snow from resting on the rounded surface between two cirque-heads.[3] As these receded,

[1] In the remainder of this Address 'temperature' is to be understood as mean temperature. The Fahrenheit scale is used.

[2] W. D. Johnson, *Science*, N.S., ix. (1899), pp. 106, 112.

[3] This does not appear to have occurred in the Alps.

only a narrow neck would be left between them, which would be ultimately cut down into a gap or 'col.' Thus a region of deep valleys with precipitous sides and heads, of sharp ridges, and of more or less isolated peaks is substituted for a rather monotonous, if lofty, highland.

The hypothesis is ingenious, but some students of Alpine scenery think more proof desirable before they can accept it as an axiom. For instance, continuous observations are necessary to justify the assumption of diurnal variations of temperature sufficient to produce any sensible effect on rock at the bottom of a narrow chasm nearly fifty yards deep and almost enclosed by ice. Here the conditions would more probably resemble those in a *glacière*, or natural ice cave. In one of these, during the summer, curtains and festoons of ice depend from the walls; from them and from the roof water drips slowly, to be frozen into stalagmitic mounds on the floor, which is itself sometimes a thick bed of ice. On this the quantity of fallen rock débris is not greater than is usual in a cave, nor are the walls notably shattered, even though a gap some four yards deep may separate them from the ice. The floors of cirques, from which the *névé* has vanished, cannot as a rule be examined, because they are masked by débris which is brought down by the numerous cascades, little and big, which seam their walls; but glimpses of them may sometimes be obtained in the smaller corries (which would be cirques if they could), and these show no signs of either 'sapping' or 'plucking,' but some little of abrasion by moving ice. Cirques and corries also not infrequently occur on the sides as well as at the heads of valleys; such, for instance, as the two in the *massif* of the Uri Rothstock on the way to the Surenen Pass and the Fer à Cheval above Sixt. The Lago di Ritom lies between the mouth of a hanging valley and a well-defined step, and just above that is the Lago di Cadagno in a large steep-walled corrie, which opens laterally into the Val Piora, as that of the Lago di Tremorgio does into the southern side of the Val Bedretto. Cirques may also be found where glaciers have had a comparatively brief existence, as the Creux des Vents on the Jura; or have never been formed, as on the slopes of Salina, one of the Lipari Islands, or in the limestone desert of Lower Egypt.[1] I have seen a miniature stepped valley carved by a rainstorm on a slope of Hampstead Heath; a cirque, about a yard in height and breadth, similarly excavated in the vertical wall of a gravel pit; and a corrie, measured by feet instead of furlongs, at the foot of one of the Binns near Burntisland, or, on a much reduced scale, in a bank of earth. On all these the same agent, plunging water, has left its marks—runlets of rain for the smaller, streams for the larger; convergent at first, perhaps, by accident,

[1] A. J. Jukes-Browne, *Geol. Mag.*, 1877, p. 477.

afterwards inevitably combined as the hollow widened and deepened. Each of the great cirques is still a 'land of streams,' and they are kept permanent for the greater part of the year by beds of snow on the ledges above its walls.

The 'sapping and plucking' process presents another difficulty—the steps already mentioned in the floors of valleys. These are supposed to indicate stages at which the excavating glacier transferred its operations to a higher level. But, if so, the outermost one must be the oldest, or the glacier must have been first formed in the lowest part of the incipient valley. Yet, with a falling temperature, the reverse would happen, for otherwise the snow must act as a protective mantle to the mature pre-glacial surface almost down to its base. However much age might have smoothed away youthful angularities, it would be strange if no receptacles had been left higher up to initiate the process; and even if sapping had only modified the form of an older valley, it could not have cut the steps unless it had begun its work on the lowest one. Thus, in the case of the Creux de Champ, if we hesitate to assume that the sapping process began at the mouth of the valley of the Grande Eau above Aigle, we must suppose it to have started somewhere near Ormont Dessus and to have excavated that gigantic hollow, the floor of which lies full 6,000 feet below the culminating crags of the Diablerets.

But even if 'sapping and plucking' were assigned a comparatively unimportant position in the cutting out of cirques and corries, it might still be maintained that the glaciers of the Ice Age had greatly deepened the valleys of mountain regions. That view is adopted by Professors Penck and Brückner in their work on the glaciation of the Alps,[1] the value of which even those who cannot accept some of their conclusions will thankfully admit. On one point all parties agree—that a valley cut by a fairly rapid stream in a durable rock is V-like in section. With an increase of speed the walls become more vertical; with a diminution the valley widens and has a flatter bed, over which the river, as the base-line is approached, may at last meander. Lateral streams will plough into the slopes, and may be numerous enough to convert them into alternating ridges and furrows. If a valley has been excavated in thick horizontal beds of rock varying in hardness, such as limestones and shales, its sides exhibit a succession of terrace walls and shelving banks, while a marked dip and other dominant structures produce their own modifications. It is also agreed that a valley excavated or greatly enlarged by a glacier should be U-like in section. But an Alpine valley, especially as we approach its head, very commonly takes the following form: For some hundreds of feet up from the torrent it is

[1] *Die Alpen in Eiszeitalter* (1909).

a distinct V; above this the slopes become less rapid, changing, say, from 45° to not more than 30°, and that rather suddenly. Still higher comes a region of stone-strewn upland valleys and rugged crags, terminating in ridges and peaks of splintered rock, projecting from a mantle of ice and snow. The V-like part is often from 800 to 1,000 feet in depth, and the above-named authors maintain that this, with perhaps as much of the more open trough above, was excavated during the Glacial Epoch. Thus the floor of any one of these valleys prior to the Ice Age must often have been at least 1,800 feet above its present level.[1] As a rough estimate we may fix the deepening of one of the larger Pennine valleys, tributary to the Rhone, to have been, during the Ice Age, at least 1,600 feet in their lower parts. Most of them are now hanging valleys; the stream issuing, on the level of the main river, from a deep gorge. Their tributaries are rather variable in form; the larger as a rule being more or less V-shaped; the shorter, and especially the smaller, corresponding more with the upper part of the larger valleys; but their lips generally are less deeply notched. Whatever may have been the cause, this rapid change in slope must indicate a corresponding change of action in the erosive agent. Here and there the apex of the V may be slightly flattened, but any approach to a real U is extremely rare. The retention of the more open form in many small elevated recesses, from which at the present day but little water descends, suggests that where one of them soon became buried under snow,[2] but was insignificant as a feeder of a glacier, erosion has been for ages almost at a standstill.

The V-like lower portion in the section of one of the principal valleys, which is all that some other observers have claimed for the work of a glacier, cannot be ascribed to subsequent modification by water, because ice-worn rock can be seen in many places, not only high up its sides, but also down to within a yard or two of the present torrent.

Thus valley after valley in the Alps seems to leave no escape from the following dilemma: Either a valley cut by a glacier does not differ in shape from one made by running water, or one which has been excavated by the latter, if subsequently occupied, is but superficially modified by ice. This, as we can repeatedly see in the higher Alpine valleys, has not succeeded in obliterating the physical features due to the ordinary processes of erosion. Even where its effects are most striking, as

[1] The amount varies in different valleys; for instance, it was fully 2,880 feet at Amsteg on the Reuss, just over 2,000 feet at Brieg in the Rhone Valley, about 1,000 feet at Guttanen in the Aare Valley, about 1,550 feet above Zermatt, and 1,100 feet above Saas Grund.

[2] My own studies of mountain districts have led me to infer that on slopes of low grade the action of snow is preservative rather than destructive. That conclusion was confirmed by Professor Garwood in a communication to the Royal Geographical Society on June 20 of the present year.

in the Spitallamm below the Grimsel Hospice, it has not wholly effaced those features; and wherever a glacier in a recent retreat has exposed a rock surface, that demonstrates its inefficiency as a plough. The evidence of such cases has been pronounced inadmissible, on the ground that the glaciers of the Alps have now degenerated into senile impotence; but in valley beds over which they passed when in the full tide of their strength the flanks show remnants of rocky ridges only partly smoothed away, and rough rock exists on the 'lee-sides' of ice-worn mounds which no imaginary plucking can explain. The ice seems to have flowed over rather than to have plunged into the obstacles in its path, and even the huge steps of limestone exposed by the last retreat of the Unter Grindelwald Glacier have suffered little more than a rounding off of their angles, though that glacier must have passed over them when in fullest development, for it seems impossible to explain these by any process of sapping.

The comparatively level trough, which so often forms the uppermost part of one of the great passes across the watershed of the Alps, can hardly be explained without admitting that in each case the original watershed has been destroyed by the more rapid recession of the head of the southern valley, and this work bears every sign of having been accomplished in pre-glacial times. Sapping and plucking must have operated on a gigantic scale to separate the Viso from the Cottian watershed, to isolate the huge pyramid of the Matterhorn, with its western spur, or to make, by the recession of the Val Macugnaga, that great gap between the Strahlhorn and Monte Rosa. Some sceptics even go so far as to doubt whether the dominant forms of a non-glaciated region differ very materially from those of one which has been half-buried in snow-fields and glaciers. To my eyes, the general outlines of the mountains about the Lake of Gennesaret and the northern part of the Dead Sea recalled those around the Lake of Annecy and on the south-eastern shore of Leman. The sandstone crags, which rise here and there like ruined castles from the lower plateau of the Saxon Switzerland, resembled in outlines, though on a smaller scale, some of the Dolomites in the Southern Tyrol. The Lofoten Islands illustrate a half-drowned mountain range from which the glaciers have disappeared. Those were born among splintered peaks and ridges, which, though less lofty, rival in form the Aiguilles of Chamonix, and the valleys become more and more ice-worn as they descend, till the coast is fringed with skerries every one of which is a *roche moutonnée*. The *névé* in each of these valleys has been comparatively ineffective; the ice has gathered strength with the growth of the glacier. As can be seen from photographs, the scenery of the heart of the Caucasus or of the Himalayas differs in scale rather than in kind from that of the Alps. Thus the amount of abrasion varies, other things

being equal, with the latitude. The grinding away of ridges and spurs, the smoothing of the walls of troughs,[1] is greater in Norway than in the Alps; it is still greater in Greenland than in Norway, and it is greatest of all in the Antarctic, according to the reports of the expeditions led by Scott and Shackleton. But even in Polar regions, under the most favourable conditions, the dominant outlines of the mountains, as shown in the numerous photographs taken by both parties, and in Dr. Wilson's admirable drawings, differ in degree rather than in kind from those of mid-European ranges. It has been asserted that the parallel sides of the larger Alpine valleys—such as the Rhone above Martigny, the Lütschine near Lauterbrunnen, and the Val Bedretto below Airolo—prove that they have been made by the ice-plough rather than by running water; but in the first I am unable to discern more than the normal effects of a rather rapid river which has followed a trough of comparatively soft rocks; in the second, only the cliffs marking the channel cut by a similar stream through massive limestones—cliffs like those which elsewhere rise up the mountain flanks far above the levels reached by glaciers; while in the third I have failed to discover, after repeated examination, anything abnormal.

Many lake basins have been ascribed to the erosive action of glaciers. Since the late Sir A. Ramsay advanced this hypothesis numbers of lakes in various countries have been carefully investigated and the results published, the most recent of which is the splendid work on the Scottish lochs by Sir J. Murray and Mr. L. Pullar.[2] A contribution to science of the highest value, it has also a deeply pathetic interest, for it is a father's memorial to a much-loved son, F. P. Pullar, who, after taking a most active part in beginning the investigation, lost his life while saving others from drowning. As the time at my command is limited, and many are acquainted with the literature of the subject, I may be excused from saying more than that even these latest researches have not driven me from the position which I have maintained from the first—namely, that while many tarns in corries and lakelets in other favourable situations are probably due to excavation by ice, as in the mountainous districts of Britain, in Scandinavia, or in the higher parts of the Alps, the difficulty of invoking this agency increases with the size of the basin—as, for example, in the case of Loch Maree or the Lake of Annecy—till it becomes insuperable. Even if Glas Llyn and Llyn Llydaw were the work of a glacier, the rock basins of Gennesaret and the Dead Sea, still more those of the great lakes in North America and in Central Africa, must be assigned to other causes.

[1] If one may judge from photographs, the smoothing of the flanks of a valley is unusually conspicuous in Milton Sound, New Zealand.

[2] *Bathymetrical Survey of the Scottish Freshwater Lochs.* Sir J. Murray and Mr. L. Pullar, 1910.

I pass on, therefore, to mention another difficulty in this hypothesis—that the Alpine valleys were greatly deepened during the Glacial Epoch—which has not yet, I think, received sufficient attention. From three to four hundred thousand years have elapsed, according to Penck and Brückner, since the first great advance of the Alpine ice. One of the latest estimates of the thickness of the several geological formations assigns 4,000 feet [1] to the Pleistocene and Recent, 13,000 to the Pliocene, and 14,000 to the Miocene. If we assume the times of deposit to be proportional to the thicknesses, and adopt the larger figure for the first-named period, the duration of the Pliocene would be 1,300,000 years, and of the Miocene 1,400,000 years. To estimate the total vertical thickness of rock which has been removed from the Alps by denudation is far from easy, but I think 14,000 feet would be a liberal allowance, of which about one-seventh is assigned to the Ice Age. But during that age, according to a curve given by Penck and Brückner, the temperature was below its present amount for rather less than half (0·47) the time. Hence it follows that, since the sculpture of the Alps must have begun at least as far back as the Miocene period, one-seventh of the work has been done by ice in not quite one-fifteenth of the time, or its action must be very potent. Such data as are at our command make it probable that a Norway glacier at the present day lowers its basin by only about 80 millimètres in 1,000 years; a Greenland glacier may remove some 421 millimètres in the same time, while the Vatnajökul in Iceland attains to 647 millimètres. If Alpine glaciers had been as effective as the last-named, they would not have removed, during their 188,000 years of occupation of the Alpine valleys, more than 121.6 metres, or just over 397 feet; and as this is not half the amount demanded by the more moderate advocates of erosion, we must either ascribe an abnormal activity to the vanished Alpine glaciers, or admit that water was much more effective as an excavator.

We must not forget that glaciers cannot have been important agents in the sculpture of the Alps during more than part of Pleistocene times. That sculpture probably began in the Oligocene period; for rather early in the next one the great masses of conglomerate, called *Nagelfluh*, show that powerful rivers had already carved for themselves valleys corresponding generally with and nearly as deep as those still in existence. Temperature during much of the Miocene period was not less than 12° F. above its present average. This would place the snow-line at about 12,000 feet.[2]

[1] I have doubts whether this is not too great.

[2] I take the fall of temperature for a rise in altitude as 1° F. for 300 feet or, when the differences in the latter are large, 3° per 1,000 feet. These estimates will, I think, be sufficiently accurate. The figures given by Hann (see for a discussion of the question, *Brit. Assoc. Report*, 1909, p. 93) work out to 1° F. for each 318 feet of ascent (up to about 10,000 feet).

In that case, if we assume the altitudes unchanged, not a snowfield would be left between the Simplon and the Maloja, the glaciers of the Pennines would shrivel into insignificance, Monte Rosa would exchange its drapery of ice for little more than a tippet of frozen snow. As the temperature fell the white robes would steal down the mountain-sides, the glaciers grow, the torrents be swollen during all the warmer months, and the work of sculpture increase in activity. Yet with a temperature even 6° higher than it now is, as it might well be at the beginning of the Pliocene period, the snow-line would be at 10,000 feet; numbers of glaciers would have disappeared, and those around the Jungfrau and the Finster Aarhorn would be hardly more important than they now are in the Western Oberland.

But denudation would begin so soon as the ground rose above the sea. Water, which cannot run off the sand exposed by the retreating tide without engraving a miniature system of valleys, would never leave the nascent range intact. The Miocene Alps, even before a patch of snow could remain through the summer months, would be carved into glens and valleys. Towards the end of that period the Alps were affected by a new set of movements, which produced their most marked effects in the northern zone from the Inn to the Durance. The Oberland rose to greater importance; Mont Blanc attained its primacy; the *massif* of Dauphiné was probably developed. That, and still more the falling temperature, would increase the snowfields, glaciers, and torrents. The first would be, in the main, protective; the second, locally abrasive; the third, for the greater part of their course, erosive. No sooner had the drainage system been developed on both sides of the Alps than the valleys on the Italian side (unless we assume a very different distribution of rainfall) would work backwards more rapidly than those on the northern. Cases of trespass, such as that recorded by the long level trough on the north side of the Maloja Kulm and the precipitous descent on the southern, would become frequent. In the interglacial episodes—three in number, according to Penck and Brückner, and occupying rather more than half the epoch—the snow and ice would dwindle to something like its present amount, so that the water would resume its work. Thus I think it far more probable that the V-like portions of the Alpine valleys were in the main excavated during Pliocene ages, their upper and more open parts being largely the results of Miocene and yet earlier sculpture.

During the great advances of the ice, four in number, according to Penck and Brückner,[1] when the Rhone glacier covered the lowlands of Vaud and Geneva, welling on one occasion over the gaps in the Jura, and leaving its erratics in the neighbourhood of Lyons, it ought to have

[1] On the exact number I have not had the opportunity of forming an opinion.

given signs of its erosive no less than of its transporting power. But what are the facts? In these lowlands we can see where the ice has passed over the Molasse (a Miocene sandstone); but here, instead of having crushed, torn, and uprooted the comparatively soft rock, it has produced hardly any effect. The huge glacier from the Linth Valley crept for not a few miles over a floor of stratified gravels, on which, some eight miles below Zurich, one of its moraines, formed during the last retreat, can be seen resting, without having produced more than a slight superficial disturbance. We are asked to credit glaciers with the erosion of deep valleys and the excavation of great lakes, and yet, wherever we pass from hypotheses to facts, we find them to have been singularly inefficient workmen!

I have dwelt at considerable, some may think undue, length on the Alps because we are sure that this region from before the close of the Miocene period has been above the sea-level. It accordingly demonstrates what effects ice can produce when working on land.

In America also, to which I must now make only a passing reference, great ice-sheets formerly existed: one occupying the district west of the Rocky Mountains, another spreading from that on the north-west of Hudson's Bay, and a third from the Laurentian hill-country. These two became confluent, and their united ice-flow covered the region of the Great Lakes, halting near the eastern coast a little south of New York, but in Ohio, Indiana, and Illinois occasionally leaving moraines only a little north of the 39th parallel of latitude.[1] Of these relics my first-hand knowledge is very small, but the admirably illustrated reports and other writings of American geologists[2] indicate that, if we make due allowance for the differences in environment, the tills and associated deposits on their continent are similar in character to those of the Alps.[3]

In our own country and in corresponding parts of Northern Europe we must take into account the possible co-operation of the sea. In these, however, geologists agree that, for at least a portion of the Ice Age, glaciers occupied the mountain districts. Here ice-worn rocks, moraines and perched blocks, tarns in corries, and perhaps lakelets in valleys, demonstrate the former presence of a mantle of snow and ice. Glaciers radiated outwards from more than one focus in Ireland, Scotland, the English Lake District, and Wales, and trespassed, at the time

[1] Some of the glacial drifts on the eastern side of the continent, as we shall find, may have been deposited in the sea.

[2] See the *Reports of the United States Geological Survey* (from vol. iii. onwards), *Journal of Geology*, *American Journal of Science*, and local publications too numerous to mention. Among these the studies in Greenland by Professor Chamberlin are especially valuable for the light they throw on the movement of large glaciers and the transport of débris in the lower part of the ice.

[3] Here, however, we cannot always be so sure of the absence of the sea.

of their greatest development, upon the adjacent lowlands. They are generally believed to have advanced and retreated more than once, and their movements have been correlated by Professor J. Geikie with those already mentioned in the Alps. Into that very difficult question I must not enter; for my present purpose it is enough to say that in early Pleistocene times glaciers undoubtedly existed in the mountain districts of Britain and even formed piedmont ice-sheets on the lowlands. On the west side of England smoothed and striated rocks have been observed near Liverpool, which can hardly be due to the movements of shore-ice, and at Little Crosby a considerable surface has been cleared from the overlying boulder clay by the exertions of the late Mr. T. M. Reade and his son, Mr. A. Lyell Reade. But, so far as I am aware, rocks thus affected have not yet been discovered in the Wirral peninsula. On the eastern side of England similar markings have been found down to the coast of Durham, but a more southern extension of land ice cannot be taken for granted. In this direction, however, so far as the tidal valley of the Thames, and in corresponding parts of the central and western lowlands, certain deposits occur which, though to a great extent of glacial origin, are in many respects different from those left by land ice in the Alpine regions and in Northern America.

They present us with problems the nature of which may be inferred from a brief statement of the facts. On the Norfolk coast we find the glacial drifts resting, sometimes on the chalk, sometimes on strata of very late Pliocene or early Pleistocene age. The latter show that in their time the strand-line must have oscillated slightly on either side of its present level. The earliest of the glacial deposits, called the Cromer Till and Contorted Drift, presents its most remarkable development in the cliffs on either side of that town. Here it consists of boulder clays and alternating beds of sand and clay; the first-named, two or three in number, somewhat limited in extent, and rather lenticular in form, are slightly sandy clays, full of pieces of chalk, flint, and other kinds of rock, some of the last having travelled from long distances. Yet more remarkable are the huge erratics of chalk, in the neighbourhood of which the sands and clays exhibit extraordinary contortions. Like the beds of till, they have not been found very far inland, for there the group appears as a whole to be represented by a stony loam, resembling a mixture of the sandy and clayey material, and this is restricted to a zone some twenty miles wide bordering the coast of Norfolk and Suffolk; not extending south of the latter county, but being probably represented to the north of the Humber. Above these is a group of false-bedded sands and gravels, variable in thickness and character—the Mid-glacial Sands of Searles V. Wood and F. W. Harmer. They extend over a wider area,

and may be traced, according to some geologists, nearly to the western side of England, rising in that direction to a greater height above sea-level. But as it is impossible to prove that all isolated patches of these materials are identical in age, we can only be certain that some of them are older than the next deposit, a boulder clay, which extends over a large part of the lowlands in the Eastern Counties. This has a general resemblance to the Cromer Till, but its matrix is rather more clayey and is variable in colour. In and north of Yorkshire, as well as on the seaward side of the Lincolnshire wolds, it is generally brownish or purplish, but on their western side and as far as the clay goes to the south it is some shade of grey. Near to these wolds, in mid-Norfolk and on the northern margin of Suffolk, it has a whitish tint, owing to the abundance of comminuted chalk. To the south and west of this area it is dark, from the similar presence of Kimmeridge clay. Yet further west it assumes an intermediate colour by having drawn upon the Oxford clay. This boulder clay, whether the chalky or the purple, in which partings of sand sometimes occur, must once have covered, according to Mr. F. W. Harmer, an area about ten thousand square miles in extent. It spreads like a coverlet over the pre-glacial irregularities of the surface. It caps the hills, attaining sometimes an elevation of fully 500 feet above sea-level;[1] it fills up valleys,[2] sometimes partly, sometimes wholly, the original floors of which occasionally lie more than 100 feet below the same level. This boulder clay, often with an underlying sand or gravel, extends to the south as far as the neighbourhood of Muswell Hill and Finchley; hence its margin runs westward through Buckinghamshire, and then, bending northwards, passes to the west of Coventry. On this side of the Pennine Chain the matrix of the boulder clay is again reddish, being mainly derived from the sands and marls of the Trias; pieces of chalk and flint are rare (no doubt coming from Antrim), though other rocks are often plentiful enough. Some authorities are of opinion that the drift in most parts of Lancashire and Cheshire is separable, as on the eastern coasts, into a lower and an upper boulder clay, with intervening gravelly sands, but others think that the association of the first and third is lenticular rather than

[1] Not far from Royston it is found at a height of 525 feet above O.D. See F. W. Harmer, *Pleistocene Period in the Eastern Counties*, p. 115.

[2] At Old North Road Station, on a tributary of the Cam, the boulder clay was pierced to a depth of 180 feet, and at Impington it goes to 60 feet below sea-level. Near Hitchin, a hidden valley, traced for seven or eight miles, was proved to a depth of 68 feet below O.D., and one near Newport in Essex to 104 feet. Depths were also found of 120 feet at West Horseheath in Suffolk, of 120 feet on low ground two miles S.W. of Sandy in Bedfordshire, of from 100 to 160 feet below the sea at Fossdyke, Long Sutton, and Boston, and at Glemsford in the valley of the Stour 477 feet of drift was passed through before reaching the chalk. See F. W. Harmer, *Quart. Journ. Geol. Soc.*, lxiii. (1907), p. 494.

successive. Here also the lower clay cannot be traced very far inland, eastward or southward; the others have a wider extension, but they reach a greater elevation above sea-level than on the eastern side of England. The sand is inconstant in thickness, being sometimes hardly represented, sometimes as much as 200 feet. The upper clay runs on its more eastern side up to the chalky boulder clay, and extends on the south at least into Worcestershire. On the western side it merges with the upper member of the drifts radiating from the mountains of North Wales, which often exhibit a similar tripartite division, while (as we learn from the officers of the Geological Survey) boulder clays and gravelly sands, which it must suffice to mention, extend from the highlands of South Wales for a considerable distance to the south-east and south. Boulder clay has not been recognised in Devon or Cornwall, though occasional erratics are found which seem to demand some form of ice-transport. A limited deposit, however, of that clay, containing boulders now and then over a yard in diameter, occurs near Selsey Bill on the Sussex coast, which most geologists consider to have been formed by floating rather than by land ice.

Marine shells are not very infrequent in the lower clays of East Anglia and Yorkshire, but are commonly broken. The well-known Bridlington Crag is the most conspicuous instance, but this is explained by many geologists as an erratic—a piece of an ancient North Sea bed caught up and transported, like the other molluscs, by an advancing ice-sheet. They also claim a derivative origin for the organic contents of the overlying sands and gravels, but some authorities consider the majority to be contemporaneous. Near the western coast of England, shells in much the same state of preservation as those on the present shore are far from rare in the lower clay, where they are associated with numerous striated stones, often closely resembling those which have travelled beneath a glacier, both from the Lake District and the less distant Trias. Shells are also found in the overlying sands up the valleys of the Dee and Severn, at occasional localities, even as far inland as Bridgnorth, the heights of the deposits varying from about 120 feet to over 500 feet above the sea-level. If we also take account of the upper boulder clay, where it can be distinguished, the list of marine molluscs, ostracods, and foraminifers from these western drifts is a rather long one.[1]

Marine shells, however, on the western side of England, are not restricted to the lowlands. Three instances, all occurring over 1,000 feet above sea-level, claim more than a passing mention. At Macclesfield, almost thirty miles in a straight line from the head of the estuary of the Mersey, boulder clays associated with stratified gravels

[1] W. Shone, *Quart. Journ. Geol. Soc.*, xxxiv. (1878), p. 383.

and sands have been described by several observers.[1] The clay stops at about 1,000 feet, but the sands and gravels go on to nearly 1,300 feet, while isolated erratics are found up to about 100 feet higher. Sea shells, some of which are in good condition, have been obtained at various elevations, the highest being about 1,200 feet above sea-level. About forty-eight species of molluscs have been recognised, and the fauna, with a few exceptions, more arctic in character and now found at a greater depth, is one which at the present day lives in a temperate climate at a depth of a few fathoms.

The shell-bearing gravels at Gloppa, near Oswestry, which are about thirty miles from the head of the Dee estuary, were carefully described in 1892 by Mr. A. C. Nicholson. He has enumerated fully sixty species, of which, however, many are rare. As his collection[2] shows, the bivalves are generally broken, but a fair number of the univalves are tolerably perfect. The deposit itself consists of alternating seams of sand and gravel, the one generally about an inch in thickness, the other varying from a few inches to a foot. The difference in the amount of rounding shown by the stones is a noteworthy feature. They are not seldom striated; some have come from Scotland, others from the Lake District, but the majority from Wales, the last being the more angular. Here and there a block, sometimes exceeding a foot in diameter and usually from the last-named country, has been dropped among the smaller material, most of which ranges in diameter from half an inch to an inch and a half. The beds in one or two places show contortions; but as a rule, though slightly wavy and with a gentle dip rather to the west of south, they are uniformly deposited. In this respect, and in the unequal wearing of the materials, the Gloppa deposit differs from most gravels that I have seen. Its situation also is peculiar. It is on the flattened top of a rocky spur from higher hills, which falls rather steeply to the Shropshire lowland on the eastern side, and on the more western is defined by a small valley which enlarges gradually as it descends towards the Severn. If the country were gradually depressed for nearly 1,200 feet, this upland would become, first a promontory, then an island, and finally a shoal.

The third instance, on Moel Tryfaen in Carnarvonshire, was carefully investigated and described by a Committee of this Association[3] about ten years ago. The shells occur in an irregularly stratified sand and gravel, resting on slate and overlain by a boulder clay, no great

[1] *Memoirs of the Geological Survey*: 'Country around Macclesfield,' T. I. Pocock (1906), p. 85. For some notes on Moel Tryfaen and the altitudes of other localities at which marine organisms have been found see J. Gwyn Jeffreys, *Quart. Journ. Geol. Soc.*, xxxvi. (1880), p. 351. For the occurrence of such remains in the Vale of Clwyd see a paper by T. McK. Hughes in *Proc. Chester Soc. of Nat. Hist.*, 1884.

[2] Now deposited in the Oswestry Museum.

[3] *Brit. Assoc. Report*, 1899 (1900), pp. 414–423.

distance from and a few dozen feet below the rocky summit of the hill, being about 1,300 feet above the level of the sea and at least five miles from its margin. About fifty-five species of molluscs and twenty-three of foraminifers have been identified. According to the late Dr. J. Gwyn Jeffreys,[1] the majority of the molluscs are littoral in habit, the rest such as live in from ten to twenty fathoms of water. Most of the erratics have been derived from the Welsh mountains, but some rocks from Anglesey have also been obtained, and a few pebbles of Lake District and Scottish rocks. If the sea were about 1,300 feet above its present level, Moel Tryfaen would become a small rocky island, open to the storms from the west and north, and nearly a mile and a half away from the nearest land.

I must pass more rapidly over Ireland. The signs of vanished glaciers — ice-worn rocks and characteristic boulder-clays — are numerous, and may be traced in places down to the sea-level, but the principal outflow of the ice, according to some competent observers, was from a comparatively low district, extending diagonally across the island from the south of Lough Neagh to north of Galway Bay. Glaciers, however, must have first begun to form in the mountains on the northern and southern side of this zone, and we should have expected that, whatever might happen on the lowlands, they would continue to assert themselves. In no other part of the British Islands are eskers, which some geologists think were formed when a glacier reached the sea, so strikingly developed. Here also an upper and a lower boulder clay, the former being the more sparsely distributed, are often divided by a widespread group of sands and gravels, which locally, as in Great Britain, contains, sometimes abundantly, shells and other marine organisms; more than twenty species of molluscs, with foraminifers, a barnacle, and perforations of annelids, having been described. These are found in counties Dublin and Wicklow, at various altitudes,[2] from a little above sea-level to a height of 1,300 feet.

Not the least perplexing of the glacial phenomena in the British Isles is the distribution of erratics, which has been already mentioned in passing. On the Norfolk coast masses of chalk, often thousands of cubic feet in volume, occur in the lowest member of the glacial series, with occasional great blocks of sand and gravel, which must have once been frozen. But these, or at any rate the larger of them, have no doubt been derived from the immediate neighbourhood. Huge erratics also occasionally occur in the upper boulder clay—sometimes of chalk, as at Roslyn Hill near Ely and at Ridlington in Rutland, of jurassic limestone, near Great Ponton, to the south of Grantham,

[1] *Quart. Journ. Geol. Soc.*, xxxvi. (1880), p. 355.
[2] See T. M. Reade, *Proc. Liverpool Geol. Soc.*, 1893–94, p. 183, for some weighty arguments in favour of a marine origin for these deposits.

and of Lower Kimmeridge clay near Biggleswade.[1] These also probably have not travelled more than a few miles. But others of smaller size have often made much longer journeys. The boulder clays of Eastern England are full of pieces of rock, commonly ranging from about half an inch to a foot in diameter. Among these are samples of the carboniferous, jurassic, and cretaceous rocks of Yorkshire and the adjacent counties; the red chalk from either Hunstanton, Speeton, or some part of the Lincolnshire wolds, being found as far south as the northern heights of London. Even the chalk and flint, the former of which, especially in the upper boulder clay, commonly occurs in well-worn pebbles, are frequently not the local but the northern varieties. And with these are mingled specimens from yet more distant sources—Cheviot porphyrites, South Scottish basalts, even some of the crystalline rocks of the Highlands. Whatever was the transporting agent, its general direction was southerly, with a slight deflection towards the east in the last-named cases.

But the path of these erratics has been crossed by two streams, one coming from the west, the other from the east. On the western side of the Pennine watershed the Shap granite rises at Wasdale Crag to a height of about 1,600 feet above sea-level. Boulders from it have descended the Eden valley to beyond Penrith; they have travelled in the opposite direction almost to Lancaster,[2] and a large number of them have actually made their way near the line of the Lake District watershed, across the upper valley of the Eden, and over the high pass of Stainmoor Forest,[3] whence they descended into Upper Teesdale. Subsequently the stream seems to have bifurcated, one part passing straight out to the present sea-bed, by way of the lower course of the Tees, to be afterwards driven back on to the Yorkshire coast. The other part crossed the low watershed between the Tees and the Ouse, descended the Vale of York, and spread widely over the plain.[4] Shap boulders by some means penetrated into the valleys tributary to the Ouse on its west bank, and they have been observed as far to the south-east as Royston, near Barnsley. It is noteworthy that Lake District rocks have been occasionally recorded from Airedale and even the neighbourhood of Colne, though the granite from Shap has not been found there. The other stream started from Scandinavia. Erratics, some of which must have come from the north-western side of the Christiania Fjord, occur on or near the coast from Essex to Yorkshire, and occasionally

[1] H. Home, *Quart. Journ. Geol. Soc.*, lix. (1903), p. 375.

[2] A pebble of it is said to have been identified at Moel Tryfaen.

[3] The lowest part of the gap is about 1,400 feet. A little to the south is another gap about 200 feet lower, but none of the boulders seem to have taken that route.

[4] A boulder was even found above Grosmont in the Eske valley, 345 feet above sea-level.

even as far north as Aberdeen, while they have been traced from the East Anglian coast to near Ware, Hitchin, and Bedford.[1] It may be important to notice that these Scandinavian erratics are often waterworn, like those dispersed over Denmark and parts of Northern Germany.

On the western side of England the course of erratics is not less remarkable. Boulders from South-Western Scotland, especially from the Kirkcudbright district, both waterworn and angular, are scattered over the lowlands as far south as Wolverhampton, Bridgnorth, and Church Stretton. They may be traced along the border of North Wales, occurring, as has been said, though generally small, up to about 1,300 feet on Moel Tryfaen, 1,100 feet at Gloppa, and more than that height on the hills east of Macclesfield. Boulders from the Lake District are scattered over much the same area and attain the same elevation, but extend, as might be expected, rather further to the east in Lancashire. They also have been found on the eastern side of the Pennine watershed, perhaps the most remarkable instances being in the dales of the Derbyshire Derwent and on the adjacent hills as much as 1,400 feet above the sea-level.[2] A third remarkable stream of erratics from the neighbourhood of the Arenig mountains extends from near the estuary of the Dee right across the paths of the two streams from the north, its eastern border passing near Rugeley, Birmingham, and Bromsgrove. They also range high, occurring almost 900 feet above sea-level on Romsley Hill, north of the Clents, and being common at Gloppa. Boulders also from the basalt mass of Rowley Regis have travelled in some cases between four and five miles, and in directions ranging from rather west of south to north-east; and, though that mass hardly rises above the 700-feet contour line, one lies with an Arenig boulder on Romsley Hill. From Charnwood Forest, the crags of which range up to about 850 feet above sea-level, boulders have started which have been traced over an area to the south and west to a distance of more than twenty miles.

Such, then, are the facts, which call for an interpretation. More than one have been proposed; but it will be well, before discussing them, to arrive at some idea of the climate of these islands during the colder part of the Glacial Epoch. Unless that were associated with very great changes in the distribution of sea and land in Northern and North-Western Europe, we may assume that neither the relative position of the isotherms nor the distribution of precipitation would be very materially altered. A general fall of temperature in the northern hemisphere might so weaken the warmer ocean current from the south-west that our coasts might be approached by a cold one from the

[1] R. H. Rastall and J. Romanes, *Quart. Journ. Geol. Soc.*, lxv. (1909), p. 246.
[2] Communication from Dr. H. Arnold-Bemrose.

opposite direction.[1] But though these changes might diminish the difference between the temperatures of London and Leipzig, they would not make the former colder than the latter. At the present day the snow-line in the Alps on either side of the Upper Rhone Valley is not far from 8,000 feet above sea-level, and this corresponds with a temperature of about 30°. Glaciers, however, are not generally formed till about 1,000 feet higher, where the temperature is approximately 27°. Penck and Brückner place this line during the coldest part of the Ice Age at about 4,000 feet.[2] In that case the temperature of the Swiss lowland would be some 15° lower than now, or near the freezing-point.[3] If this fall were general, it would bring back the small glaciers on the Gran Sasso d'Italia and Monte Rotondo in Corsica; perhaps also among the higher parts of the Vosges and Schwarzwald.[4] In our own country it would give a temperature of about 35° at Carnarvon and 23° on the top of Snowdon, of 32° at Fort William and 17°.5 on the top of Ben Nevis. If, in addition to this, the land were 600 feet higher than now (as it probably was, at any rate in the beginning of the Glacial Epoch), there would be a further drop of 2°, so that glaciers would form in the corries of Snowdon, and the region round Ben Nevis might resemble the Oetzthal Alps at the present day. This change of itself would be insufficient, and any larger drop in the ocean-level would have to be continental in its effects, since we cannot assume a local upheaval of much more than the above amount without seriously interfering with the river system of North Central Europe. But these changes, especially the former, might indirectly diminish the abnormal warmth of winter on our north-western coasts.[5] It is difficult to estimate the effect of this. If it did no more than place Carnarvon on the isotherm of Berlin (now lower by 2°), that would hardly bring a glacier from the Snowdonian region down to the sea. At the present time London is about 18° warmer than a place in the same latitude near the Labrador coast or the mouth of the Amur River, but the removal of that difference would involve greater changes in the distribution of sea and land than seems possible at an epoch comparatively speaking so recent.

[1] Facts relating to this subject will be found in *Climate and Time*, by J. Croll, ch. ii. and iii. (1875). Of course the air currents would also be affected, and perhaps diminish precipitation as the latitude increased.

[2] *Loc. cit.*, p. 586, *et seq.* They say the snow-line, which would mean that the temperature was only 12° lower than now; but as possibly this line might then more nearly correspond with that of glacier formation, I will provisionally accept the higher figures, especially since Corsica, the Apennines, and some other localities in Europe, seem to require a reduction of rather more than 12°.

[3] It would be 32°.5 at Zurich, 31°.6 at Bern, 34°.1 at Geneva, about 39°.0 on the plain of Piedmont, and 36°. at Lyons.

[4] See for particulars the author's *Ice Work* ('International Scientific Series'), p. 237.

[5] For much valuable information on these questions see a paper on the Climate of the Pleistocene Epoch (F. W. Harmer, *Quart. Journ. Geol. Soc.*, lvii. (1901), p. 405).

I am doubtful whether we can attribute to changed currents a reduction in British temperatures of so much as 11°; but, if we did, this would amount to 28° from all causes, and give a temperature of 20° to 22° at sea-level in England during the coldest part of the Glacial Epoch.[1] That is now found, roughly speaking, in Spitsbergen, which, since its mountains rise to much the same height, should give us a general idea of the condition of Britain in the olden time.

What would then be the state of Scandinavia? Its present temperature ranges on the west coast from about 45° in the south to 35° in the north.[2] But this region must now be very much, possibly 1,800 feet, lower than it was in pre-glacial, perhaps also in part of glacial, times.[3] If we added 5° for this to the original 15°, and allowed so much as 18° for the diversion of the warm current, the temperature of Scandinavia would range from 7° to −3°, approximately that of Greenland northwards from Upernivik. But since the difference at the present day between Cape Farewell and Christiania (the one in an abnormally cold region, the other in one correspondingly warm) is only 7°, that allowance seems much too large, while without it Scandinavia would correspond in temperature with some part of that country from south of Upernivik to north of Frederikshaab.[4] But if Christiania were not colder than Jakobshavn is now, or Britain than Spitsbergen, we are precluded from comparisons with the coasts of Baffin Bay or Victoria Land.

Thus the ice-sheet from Scandinavia would probably be much greater than those generated in Britain. It would, however, find an obstacle to progress westwards, which cannot be ignored. If the bed of the North Sea became dry land, owing to a general rise of 600 feet, that would still be separated from Norway by a deep channel, extending from the Christiania Fjord round the coast northward. Even then this would be everywhere more than another 600 feet deep, and almost as wide as the Strait of Dover.[5] The ice must cross this and afterwards be forced for more than 300 miles up a slope, which, though gentle, would be in vertical height at least 600 feet. The task, if accomplished by

[1] The present temperature in Ireland over the zone (from S. of Belfast to N. of Galway Bay) which is supposed to have formed the divide of the central snowfield may be given as from 49° to 50°, nearly the same as at the sea-level in Carnarvonshire. Thus, though the district is less mountainous than Wales, it would not need a greater reduction, for the snowfall would probably be rather larger. But this reduction could hardly be less than 20°, for the glaciers would have to form nearly at the present sea-level.

[2] It is 44°.42 at Bergen, 38°.48 at Bodo, 35°.42 at Hammerfest, 41°.36 at Christiania and Stockholm.

[3] For particulars see *Geol. Mag.*, 1899, p. 97 (W. H. Hudleston) and p. 282 (T. G. Bonney).

[4] Christiania and Cape Farewell (Greenland) are nearly on the same latitude.

[5] For details see *Geol. Mag.*, 1899, pp. 97 and 282.

thrust from behind, would be a heavy one, and, so far as I know, without a parallel at the present day; if the viscosity of the ice enabled it to flow, as has lately been urged,[1] we must be cautious in appealing to the great Antarctic barrier, because we now learn that more than half of it is only consolidated snow.[2] Moreover, if the ice floated across that channel, the thickness of the boulder-bearing layers would be diminished by melting (as in Ross's Barrier), and the more viscous the material the greater the tendency for these to be left behind by the overflow of the cleaner upper layers. If, however, the whole region became dry land, the Scandinavian glaciers would descend into a broad valley, considerably more than 1,200 feet deep, which would afford them an easy path to the Arctic Ocean, so that only a lateral overflow, inconsiderable in volume, could spread itself over the western plateau.[3] An attempt to escape this difficulty has been made by assuming the existence of an independent centre of distribution for ice and boulders near the middle of the North Sea bed[4] (which would demand rather exceptional conditions of temperature and precipitation); but in such case either the Scandinavian ice would be fended off from England, or the boulders, prior to its advance, must have been dropped by floating ice on the neighbouring sea-floor.

If, then, our own country were but little better than Spitsbergen as a producer of ice, and Scandinavia only surpassed Southern Greenland in having a rather heavier snowfall, what interpretation may we give to the glacial phenomena of Britain? Three have been proposed. One asserts that throughout the Glacial Epoch the British Isles generally stood at a higher level, so that the ice which almost buried them flowed out on to the beds of the North and Irish Seas. The boulder clays represent its moraines. The stratified sands and gravels were deposited in lakes formed by the rivers which were dammed up by ice-sheets.[5] A second interpretation recognises the presence of glaciers in the mountain regions, but maintains that the land, at the outset rather above its present level, gradually sank beneath the sea, till the depth of water over the eastern coast of England was fully 500 feet, and

[1] H. M. Deeley, *Geol. Mag.*, 1909, p. 239.

[2] E. Shackleton, *The Heart of the Antarctic*, ii. 277.

[3] It has indeed been affirmed (Brögger, *Om de senglaciale og postglaciale nivaforandringer i Kristianiafeltet*, p. 682) that at the time of the great ice-sheet of Europe the sea-bottom must have been uplifted at least 8,500 feet higher than at present. This may be a ready explanation of the occurrence of certain dead shells in deep water, but, unless extremely local, it would revolutionise the drainage system of Central Europe.

[4] *Geol. Mag.*, 1901, pp. 142, 187, 284, 332.

[5] See Warren Upham, *Monogr. U.S. Geol. Survey*, xxv. (1896). This explanation commends itself to the majority of British geologists as an explanation of the noted parallel roads of Glenroy, but it is premature to speak of it as 'conclusively shown' (*Quart. Journ. Geol. Soc.*, lviii. (1902), 473) until a fundamental difficulty which it presents has been discussed and removed.

over the western nearly 1,400 feet, from which depression it slowly recovered. By any such submergence Great Britain and Ireland would be broken up into a cluster of hilly islands, between which the tide from an extended Atlantic would sweep eastwards twice a day, its currents running strong through the narrower sounds, while movements in the reverse direction at the ebb would be much less vigorous. The third interpretation, in some respects intermediate, was first advanced by the late Professor Carvill Lewis, who held that the peculiar boulder clays and associated sands (such as those of East Anglia), which, as was then thought, were not found more than about 450 feet above the present sea-level, had been deposited in a great fresh-water lake, held up by the ice-sheets already mentioned and by an isthmus, which at that time occupied the place of the Strait of Dover. Thus, these deposits, though indirectly due to land-ice, were actually fluviatile or lacustrine. But this interpretation need not detain us, though the former existence of such lakes is still maintained, on a small scale in Britain, on a much larger one in North America, because, as was pointed out when it was first advanced, it fails to explain the numerous erratic blocks and shell-bearing sands which occur far above the margin of the hypothetical lake.

Each of the other two hypotheses involves grave difficulties. That of great confluent ice-sheets creeping over the British lowlands demands, as has been intimated, climatal conditions which are scarcely possible, and makes it hard to explain the sands and gravels, sometimes with regular alternate bedding, but more generally indicative of strong current action, which occur at various elevations to over 1,300 feet above sea-level, and seem too widespread to have been formed either beneath an ice-sheet or in lakes held up by one; for the latter, if of any size, would speedily check the velocity of influent streams. Also the mixture and crossing of boulders, which I have described, are inexplicable without the most extraordinary oscillations in the size of the contributing glaciers. To suppose that the Scandinavian ice reached to Bedfordshire and Herts and then retired in favour of North British glaciers, or *vice versâ*, assumes an amount of variation which, so far as I am aware, is without a parallel elsewhere. So also the mixture of boulders from South Scotland, the Lake District, and North Wales which lie, especially in parts of Staffordshire and Shropshire, as if dropped upon the surface, far exceeds what may reasonably be attributed to variations amplified by lateral spreading of mountain glaciers on reaching a lowland, while the frequent presence of shells in the drifts, dozens of miles away from the present coast, implies a rather improbable scooping up of the sea-bed without much injury to such fragile objects. The ice also must have been curiously inconstant in

its operations. It is supposed in one place to have glided gently over its bed, in another to have gripped and torn out huge masses of rock.[1] Both actions may be possible in a mountain region, but it is very difficult to understand how they could occur in a lowland or plain. Besides this we can only account for some singular aberrations of boulders, such as Shap granite well above Grosmont in Eskdale, or the Scandinavian rhomb-porphyry above Lockwood,[2] near Huddersfield, by assuming a flexibility in the lobes of an ice-sheet which it is hard to match at the present time. Again, the boulder clay of the Eastern Counties is crowded, as we have described, with pebbles of chalk, which generally are not of local origin, but have come from north of the Wash. Whether from the bed of a river or from a sea-beach, they are certainly water-worn. But if preglacial, the supply would be quickly exhausted, so that they would usually be confined to the lower part of the clay. As it is, though perhaps they run larger here, they abound throughout. The so-called moraines near York (supposed to have been left by a glacier retreating up that vale), those in the neighbourhood of Flamborough Head and of Sheringham (regarded as relics of the North Sea ice-sheet) do not, in my opinion, show any important difference in outline from ordinary hills of sands and gravels, and their materials are wholly unlike those of any indubitable moraines that I have either seen or studied in photographs. It may be said that the British glaciers passed over very different rocks from the Alpine; but the Swiss molasse ought to have supplied abundant sand, and the older interglacial gravels quantities of pebbles; yet the differences between the morainic materials on the flank of the Jura or near the town of Geneva and those close to the foot of the Alps are varietal rather than specific.

Some authorities, however, attribute such magnitude to the ice-sheets radiating from Scandinavia that they depict them, at the time of maximum extension, as not only traversing the North Sea bed and trespassing upon the coast of England, but also radiating southward to overwhelm Denmark and Holland, to invade Northern Germany and Poland, to obliterate Hanover, Berlin, and Warsaw, and to stop but little short of Dresden and Cracow, while burying Russia on the east to within no great distance of the Volga and on the south to the neighbourhood of Kief. Their presence, however, so far as I can ascertain, is inferred from evidence[3] very similar to that which we have discussed in the

[1] That this has occurred at Cromer is a very dubious hypothesis (see *Geol. Mag.*, 1905, pp. 397, 524). The curious relations of the drift and chalk in the islands of Möen and Rügen are sometimes supposed to prove the same action. Knowing both well, I have no hesitation in saying that the chalk there is, as a rule, as much *in situ* as it is in the Isle of Wight.

[2] About half-way across England and 810 feet above sea-level. P. F. Kendall, *Quart. Journ. Geol. Soc.*, lviii. (1902), p. 498.

[3] A valuable summary of it is given in *The Great Ice Age*, J. Geikie, ch. xxix., xxx. (1894).

British lowlands. That Scandinavia was at one time almost wholly buried beneath snow and ice is indubitable; it is equally so that at the outset the land stood above its present level, and that during the later stages of the Glacial Epoch parts, at any rate of Southern Norway, had sunk down to a maximum depth of 800 feet. In Germany, however, erratics are scattered over its plain and stranded on the slopes of the Harz and Riesengebirge up to about 1,400 feet above sea-level. The glacial drifts of the lowlands sometimes contain dislodged masses of neighbouring rocks like those at Cromer, and we read of other indications of ice action. I must, however, observe that since the glacial deposits of Möen, Warnemünde, and Rügen often present not only close resemblances to those of our Eastern Counties but also very similar difficulties, it is not permissible to quote the one in support of the other, seeing that the origin of each is equally dubious. Given a sufficient 'head' of ice in northern regions, it might be possible to transfer the remains of organisms from the bed of the Irish Sea to Moel Tryfaen, Macclesfield, and Gloppa; but at the last-named, if not at the others, we must assume the existence of steadily alternating currents in the lakes in order to explain the corresponding bedding of the deposit. This, however, is not the only difficulty. The 'Irish Sea glacier' is supposed to have been composed of streams from Ireland, South-West Scotland, and the Lake District, of which the second furnished the dominant contingent; the first-named not producing any direct effect on the western coast of Great Britain, and the third being made to feel its inferiority and 'shouldered in upon the mainland.' But even if this ever happened, ought not the Welsh ice to have joined issue with the invaders a good many miles to the north of its own coast?[1] Welsh boulders at any rate are common near the summit of Moel Tryfaen, and I have no hesitation in saying that the pebbles of riebeckite-rock, far from rare in its drifts, come from Mynydd Mawr, hardly half a league to the E.S.E., and not from Ailsa Craig.[2]

As such frequent appeal is made to the superior volume of the ice-sheet which poured from the Northern Hills over the bed of the Irish Sea, I will compare in more detail the ice-producing capacities of the

[1] From Moel Tryfaen to the nearest point of Scotland is well over a hundred miles, and it is a few less than this distance from Gloppa to the Lake District. In order to allow the Irish Sea ice-sheet to reach the top of Moel Tryfaen the glacier productive power of Snowdonia has been minimised (Wright, *Man and the Glacial Epoch*, pp. 171, 172). But the difference between that and the Arenig region is not great enough to make the one incompetent to protect its own borderland while the other could send an ice-sheet which could almost cover the Clent Hills and reach the neighbourhood of Birmingham. Anglesey also, if we suppose a slight elevation and a temperature of 29° at the sea-level, would become a centre of ice-distribution and an advance guard to North Wales.

[2] The boulders of picrite near Porth Nobla, from Llanerchymedd, though they have travelled southward, have moved away much to the west.

several districts. The present temperature of West-Central Scotland may be taken as 47°; its surface as averaging about 2,500 feet, rising occasionally to nearly 4,000 feet above sea-level. In the western part of the Southern Uplands the temperature is a degree higher, and the average for altitude at most not above 1,500 feet. In the Lake District and the Northern Pennines the temperature is increased by another degree, and the heights are, for the one 1,800 feet with a maximum of 3,162 feet, for the other 1,200 feet and 2,892 feet. In North Wales the temperature is 50°, the average height perhaps 2,000 feet, and the culminating point 3,571 feet. For the purpose of comparing the ice-producing powers of these districts we may bring them to one temperature by adding 300 feet to the height for each degree below that of the Welsh region. This would raise the average elevation of Central and Southern Scotland to 3,400 feet and 2,100 feet respectively; for the Lake District and Northern Pennines to 2,100 feet and 1,500 feet. We may picture to ourselves what this would mean, if the snow-line were at the sea-level in North Wales, by imagining 8,000 feet added to its height and comparing it with the Alps. North Wales would then resemble a part of that chain which had an average height of about 10,000 feet above sea-level, and culminated in a peak of 11,571 feet; the Lake District would hardly differ from it; the Northern Pennines would be like a range of about 9,000 feet, its highest peak being 11,192 feet. Southern Scotland would be much the same in average height as the first and second, and would rise, though rarely, to above 11,000 feet; the average in Central Scotland would be about 11,400 feet, and the maximum about 13,000 feet. Thus, North Wales, the Lake District, and the Southern Uplands would differ little in ice-productive power; while Central Scotland would distinctly exceed them, but not more than the group around the Finsteraarhorn does that giving birth to the Rhone glacier. In one respect, however, all these districts would differ from the Alps—that, at 8,000 feet, the surface, instead of being furrowed with valleys, small and great, would be a gently shelving plateau, which would favour the formation of piedmont glaciers. Still, unless we assume the present distribution of rainfall to be completely altered (for which I do not know any reason), the relative magnitudes of the ice coming from these centres (whether separate glaciers or confluent sheets) could differ but little. Scottish ice would not appreciably 'shoulder inland' that from the Lake District, nor would the Welsh ice be imprisoned within its own valleys.

During the last few years, however, the lake-hypothesis of Carvill Lewis has been revived under a rather different form by some English advocates of land-ice. For instance, the former presence of ice-dammed lakes is supposed to be indicated in the upper parts of the Cleveland Hills by certain overflow channels. I may be allowed to

observe that, though this view is the outcome of much acute observation and reasoning,[1] it is wholly dependent upon the ice-barriers already mentioned, and that if they dissolve before the dry light of sceptical criticism, the lakes will 'leave not a rack behind.' I must also confess that to my eyes the so-called 'overflow channels' much more closely resemble the remnants of ancient valley-systems, formed by only moderately rapid rivers, which have been isolated by the trespass of younger and more energetic streams, and they suggest that the main features of this picturesque upland were developed before rather than after the beginning of the Glacial Epoch. I think that even 'Lake Pickering,' though it has become an accepted fact with several geologists of high repute, can be more simply explained as a two-branched 'valley of strike,' formed on the Kimmeridge clay, the eastern arm of which was beheaded, even in preglacial times, by the sea.[2] As to Lake Oxford,[3] I must confess myself still more sceptical. Some changes no doubt have occurred in later glacial and postglacial times; valleys have been here raised by deposit, there deepened sometimes by as much as 100 feet; the courses of lowland rivers may occasionally have been altered; but I doubt whether, since those times began, either ice-sheet or lake has ever concealed the site of that University city.

The submergence hypothesis assumes that, at the beginning of the Glacial Epoch, our islands stood rather above their present level, and during that period gradually subsided, on the west to a greater extent than on the east, till at last the movement was reversed, and they returned nearly to their former position. During most of this time glaciers came down to the sea from the more mountainous islands, and in winter an ice-foot formed upon the shore. This, on becoming detached, carried away boulders, beach pebbles, and finer detritus. Great quantities of the last also were swept by swollen streams into the estuaries and spread over the sea-bed by coast currents, settling down especially in the quiet depths of submerged valleys. Shore-ice in Arctic regions, as Colonel H. W. Feilden[4] has described, can striate stones and even the rock beneath it, and is able, on a subsiding area, gradually to push boulders up to a higher level. In fact the state of the British region in those ages would not have been unlike that still existing near the coasts of the Barents and Kara Seas. Over the submerged region southward, and in some cases more or less eastward, currents would

[1] P. F. Kendall, *Quart. Journ. Geol. Soc.*, lviii. (1902), 471.

[2] See for instance the courses of the Medway and the Beult over the Weald clay (C. Le Neve Foster and W. Topley, *Quart. Journ. Geol. Soc.*, xxi. (1865), p. 443).

[3] F. W. Harmer, *Quart. Journ. Geol. Soc.*, lxiii. (1907), p. 470.

[4] *Quart. Journ. Geol. Soc.*, xxxiv. (1878), p. 556.

be prevalent; though changes of wind[1] would often affect the drift of the floating ice-rafts. But though the submergence hypothesis is obviously free from the serious difficulties which have been indicated in discussing the other one, gives a simple explanation of the presence of marine organisms, and accords with what can be proved to have occurred in Norway, Waigatz Island, Novaia Zemlya, on the Lower St. Lawrence, in Grinnell Land, and elsewhere,[2] it undoubtedly involves others. One of them—the absence of shore terraces, caves, or other sea marks—is perhaps hardly so grave as it is often thought to be. It may be met by the remark that unless the Glacial Age lasted for a very long time and the movements were interrupted by well-marked pauses, we could not expect to find any such record. In regard also to another objection, the rather rare and sporadic occurrence of marine shells, the answer would be that, on the Norway coast, where the ice-worn rock has certainly been submerged, sea-shells are far from common and occur sporadically in the raised deltaic deposits of the fjords.[3] An advocate of this view might also complain, not without justice, that, if he cited an inland terrace, it was promptly dismissed as the product of an ice-dammed lake, and his frequent instances of marine shells in stratified drifts were declared to have been transported from the sea by the lobe of an ice-sheet; even if they have been carried across the path of the Arenig ice, more than forty miles, as the crow flies, from the Irish Sea up the Valley of the Severn, or forced some 1,300 feet up Moel Tryfaen.[4] The difficulty in the latter case, he would observe, is not met by saying the ice-sheet would be able to climb that hill 'given there were a sufficient head behind it.'[5] That ice can be driven uphill has long been known, but the existence of the 'sufficient head' must be demonstrated, not assumed. There may be 'no logical halting-place between an uplift of ten or twenty feet to surmount a *roche moutonnée* and an equally gradual

[1] See p. 25, and for the currents now dominant consult Dr. H. Bassett in Professor Herdman's Report on the Lancashire Sea Fisheries, *Trans. Biol. Soc. Liverpool*, xxiv. (1910), p. 123.

[2] See *Ice Work*, p. 221, and *Geol. Mag.*, 1900, p. 289.

[3] If, as seems probable, the temperature was changing rather rapidly the old fauna would be pauperised and the new one make its way but slowly into the British fjords.

[4] Critics of the submergence hypothesis seem to find a difficulty in admitting downward and upward movements, amounting sometimes to nearly 1,400 feet during Pleistocene Ages; but in the northern part of America the upheaval, at any rate, has amounted to about 1,000 feet, while on the western coast, beneath the lofty summit of Mount St. Elias, marine shells of existing species have been obtained some 5,000 feet above sea-level. It is also admitted that in several places the preglacial surface of the land was much above its present level. On the Red River, whatever be the explanation, foraminifers, radiolarians, and sponge spicules have been found at 700 feet above sea-level, and near Victoria, on the Saskatchewan, even up to about 1,900 feet.

[5] P. F. Kendall in Wright's *Man and the Glacial Period*, p. 171.

elevation to the height of Moel Tryfaen,' yet there is a common-sense limitation, even to a destructive *sorites*. The argument, in fact, is more specious than valid, till we are told approximately how thick the northern ice must be to produce the requisite pressure, and whether such an accumulation would be possible. The advocates of land-ice admit that, before it had covered more than a few leagues on its southward journey its thickness was less than 2,000 feet, and we are not entitled, as I have endeavoured to show, to pile up ice indefinitely on either our British highlands or the adjacent sea-bed. The same reason also forbids us largely to augment the thickness of the latter by the snowfall on its surface, as happens to the Antarctic barrier-ice. Even if the thickness of the ice-cap over the Dumfries and Kirkcudbright hills had been about 2,500 feet, that, with every allowance for viscosity, would hardly give us a head sufficient to force a layer of ice from the level of the sea-bed to a height of nearly 1,400 feet above it and at a distance of more than 100 miles.

Neither can we obtain much support from the instance in Spitsbergen, described by Professors Garwood and Gregory, where the Ivory Glacier, after crossing the bed of a valley, had transported marine shells and drift from the floor (little above sea-level) to a height of about 400 feet on the opposite slope. Here the valley was narrow, and the glacier had descended from an inland ice-reservoir, much of which was at least 2,800 feet above the sea, and rose occasionally more than a thousand feet higher.[1]

But other difficulties are far more grave. The thickness of the chalky boulder clay alone, as has been stated, not infrequently exceeds 100 feet, and, though often much less, may have been reduced by denudation. This is an enormous amount to have been transported and distributed by floating ice. The materials also are not much more easily accounted for by this than by the other hypothesis. A continuous supply of well-worn chalk pebbles might indeed be kept up from a gradually rising or sinking beach, but it is difficult to see how, until the land had subsided for at least 200 feet, the chalky boulder clay could be deposited in some of the East Anglian valleys or on the Leicestershire hills. That depression, however, would seriously diminish the area of exposed chalk in Lincolnshire and Yorkshire, and the double of it would almost drown that rock. Again, the East Anglian boulder clay, as we have said, frequently abounds in fragments and finer detritus from the Kimmeridge and Oxford clays. But a large part of their outcrop would disappear before the former submergence was completed. Yet the materials of the boulder clay, though changing as it is traced across the country, more especially from east to west, seem to vary little in a

[1] *Quart. Journ. Geol. Soc.*, liv. (1898), p. 205. Earlier observations of some upthrust of materials by a glacier are noted on p. 219.

vertical direction. The instances, also, of the transportation of boulders and smaller stones to higher levels, sometimes large in amount, as in the transference of 'brockram' from outcrops near the bed of the Eden valley to the level of Stainmoor Gap, seem to be too numerous to be readily explained by the uplifting action of shore-ice in a subsiding area. Such a process is possible, but I should anticipate it would be rather exceptional.

Submergence also readily accounts for the above-named sands and gravels, but not quite so easily for their occurrence at such very different levels. On the eastern side of England gravelly sands may be found beneath the chalky boulder clay from well below sea-level to three or four hundred feet above it. Again, since, on the submergence hypothesis, the lower boulder clay about the estuaries of the Dee and the Mersey must represent a deposit from piedmont ice in a shallow sea, the mid-glacial sand (sometimes not very clearly marked in this part) ought not to be more than forty or fifty feet above the present Ordnance datum. But at Manchester it reaches over 200 feet, while near Heywood it is at least 425 feet. In other words the sands and gravels, presumably (often certainly) mid-glacial, mantle, like the upper boulder clay, over great irregularities of the surface, and are sometimes found, as already stated, up to more than 1,200 feet. Either of these deposits may have followed the sea-line upwards or downwards, but that explanation would almost compel us to suppose that the sand was deposited during the submergence and the upper clay during the emergence; so that, with the former material, the higher in position is the newer in time, and with the latter the reverse. We must not, however, forget that in the island of Rügen we find more than one example of a stratified gravelly sand between two beds of boulder clay (containing Scandinavian erratics) which present some resemblance to the boulder clays of eastern England, while certain glacial deposits at Warnemünde, on the Baltic coast, sometimes remind us of the Contorted Drift of Norfolk.

Towards the close of the Glacial Epoch the deposition of the boulder clay ceased [1] and its denudation began. On the low plateaux of the Eastern Counties it is often succeeded by coarse gravels, largely composed of flint, more or less water-worn. These occasionally include small intercalations of boulder clay, have evidently been derived from it, and indicate movement by fairly strong currents. Similar gravels are found overlying the boulder clay in other parts of England, sometimes at greater heights above sea-level. Occasionally the two are intimately related. For instance, a pit on the broad, almost level, top of the Gogmagog Hills, about 200 feet above sea-level and four miles south of Cambridge, shows a current-bedded sand and gravel, overlain by a

[1] Probably deposits of a distinctly glacial origin (such as those near Hessle in Yorkshire) continued in the northern districts, but on these we need not linger.

boulder clay, obviously rearranged; while other pits in the immediate neighbourhood expose varieties and mixtures of one or the other material. But, as true boulder clay occurs in the valley below, these gravels must have been deposited, and that by rather strong currents, on a hill-top—a thing which seems impossible under anything like the existing conditions; and, even if the lowland were buried beneath ice full 200 feet in thickness, which made the hill-top into the bed of a lake, it is difficult to understand how the waters of that could be in rapid motion. Rearranged boulder clays also occur on the slopes of valleys [1] which may be explained, with perhaps some of the curious sections near Sudbury, by the slipping of materials from a higher position. But at Old Oswestry gravels with indications of ice action are found at the foot of the hills almost 700 feet below those of Gloppa.

Often the plateau gravels are followed at a lower level by terrace gravels,[2] which descend towards the existing rivers, and suggest that valleys have been sometimes deepened, sometimes only re-excavated. The latter gravels are obviously deposited by rivers larger and stronger than those which now wind their way seawards, but it is difficult to explain the former gravels by any fluviatile action, whether the water from a melting ice-sheet ran over the land or into a lake, held up by some temporary barrier. But the sorting action of currents in a slowly shallowing sea would be quite competent to account for them, so they afford an indirect support to the hypothesis of submergence. It is, however, generally admitted that there have been oscillations both of level and of climate since any boulder clay was deposited in the districts south of the Humber and the Ribble. The passing of the Great Ice Age was not sudden, and glaciers may have lingered in our mountain regions when palæolithic man hunted the mammoth in the valley of the Thames, or frequented the caves of Devon and Mendip. But of these times of transition before written history became possible, and of sundry interesting topics connected with the Ice Age itself—of its cause, date, and duration, whether it was persistent or interrupted by warmer episodes, and, if so, by what number, of how often it had already recurred in the history of the earth—I must, for obvious reasons, refrain from speaking, and content myself with having endeavoured to place before you the facts of which, in my opinion, we must take account in reconstructing the physical geography of Western Europe, and especially of our own country, during the Age of Ice.

Not unnaturally you will expect a decision in favour of one or the other litigant after this long summing-up. But I can only say that, in regard to the British Isles, the difficulties in either hypothesis appear so

[1] For instance, at Stanningfield in the valley of the Lark.
[2] These contain the instruments worked by palæolithic (Acheulean) man who, in this country at any rate, is later than the chalky boulder clay.

great that, while I consider those in the 'land-ice' hypothesis to be the more serious, I cannot as yet declare the other one to be satisfactorily established, and think we shall be wiser in working on in the hope of clearing up some of the perplexities. I may add that, for these purposes, regions like the northern coasts of Russia and Siberia appear to me more promising than those in closer proximity to the North or South Magnetic Poles. This may seem a 'lame and impotent conclusion' to so long a disquisition, but there are stages in the development of a scientific idea when the best service we can do it is by attempting to separate facts from fancies, by demanding that difficulties should be frankly faced instead of being severely ignored, by insisting that the giving of a name cannot convert the imaginary into the real, and by remembering that if hypotheses yet on their trial are treated as axioms, the result will often bring disaster, like building a tower on a foundation of sand. To scrutinise, rather than to advocate any hypothesis, has been my aim throughout this address, and, if my efforts have been to some extent successful, I trust to be forgiven, though I may have trespassed on your patience and disappointed a legitimate expectation.

REPORTS

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The Further Tabulation of Bessel Functions.—Report of the Committee, consisting of Professor M. J. M. HILL (*Chairman*), Dr. J. W. NICHOLSON (*Secretary*), Professor ALFRED LODGE, *and* Dr. L. N. G. FILON.

THE Committee, having now practically completed their proposed calculations of the Bessel Functions of type $J_n(x)$, are proceeding to a calculation on similar lines of the functions $I_n(x)$ and $K_n(x)$ for various values of n and x. The former is the function of which, for the cases $n=0$ and $n=1$, extensive tables were published by the British Association in 1889, 1893, and 1896, and is defined by

$$I_n(x) = i^{-n} J_n(ix).$$

The function $K_n(x)$ satisfies the same differential equation as $I_n(x)$ and vanishes for an infinite argument. It may be conveniently defined by the integral

$$K_n(x) = \frac{\pi^{\frac{1}{2}}}{\Gamma(n+\frac{1}{2})}\left(\frac{x}{2}\right)^n \int_0^\infty d\phi \sinh^{2n}\phi \, e^{-x\cosh\phi}.$$

Writing

$$I_n(x) = \left(\frac{T_n}{2\pi x}\right)^{\frac{1}{2}} e^{t_n}.$$

$$K_n(x) = \left(\frac{\pi T_n}{2x}\right)^{\frac{1}{2}} e^{-t_n}.$$

where T_n, t_n are new functions, then it may be shown that T_n is the function R hitherto used by the Committee, with its alternate signs changed to negative. As the material for the calculation of R is still at hand, that of T_n will thus present no difficulty. It is proposed to tabulate T_n for all the available values and thence to deduce t_n from the tables for $I_n(x)$, checking the results by a recurrence formula for t_n valid when n is half an odd integer. The tabulation of $K_n(x)$ will then follow.

The results so far obtained are not sufficiently advanced to appear in the present Report.

During the course of the year Dr. Filon has found it necessary to resign the secretaryship of the Committee, and, at the request of the Chairman, Dr. Nicholson has taken up the duties.

The Committee have given further consideration to the suggestion that they should undertake the publication of a volume containing all the tables of Bessel functions and other allied functions now existent, and that their work should be directed towards the filling up of serious gaps which such a volume would contain. They view this suggestion with favour, and seek the necessary permission from the Association. A list of the existing tables has been compiled, and is now believed to be complete. The Committee are desirous of reappointment, again without a grant.

Experiments for Improving the Construction of Practical Standards for Electrical Measurements.—Report of the Committee, consisting of LORD RAYLEIGH (*Chairman*), DR. R. T. GLAZEBROOK (*Secretary*), Professors J. PERRY, W. G. ADAMS, *and* G. CAREY FOSTER, Sir OLIVER LODGE, Dr. A. MUIRHEAD, Sir W. H. PREECE, Professors A. SCHUSTER, J. A. FLEMING, *and* Sir J. J. THOMSON, Dr. W. N. SHAW, Dr. J. T. BOTTOMLEY, Rev. T. C. FITZPATRICK, Dr. G. JOHNSTONE STONEY, Professor S. P. THOMPSON, Mr. J. RENNIE, Principal E. H. GRIFFITHS, Sir ARTHUR RÜCKER, Professor H. L. CALLENDAR, *and* Messrs. G. MATTHEY, T. MATHER, *and* F. E. SMITH.

THE Report of the International Conference on Electrical Units and Standards held in London in October 1908 was printed as an Appendix to last year's Report.

In January 1910 the Board of Trade took action in accordance with the recommendations of the Report, and an Order in Council relating to electrical units, dated January 10, which contains definitions of the English standards of resistance, current, and electromotive force in conformity with the definitions adopted by the Congress, has been issued. This is printed as an Appendix.

In accordance with a scheme approved by the International Scientific Committee appointed by Lord Rayleigh at the London Conference, international co-operative work on electric standards has this year been carried out at the Bureau of Standards, Washington. It was arranged that representatives of the Bureau of Standards, the Laboratoire Central d'Electricité, Paris, the Physikalisch-Technische Reichsanstalt, Berlin, and of the National Physical Laboratory should take part in the work. The representatives of the Bureau of Standards were Professor E. B. Rosa and Dr. F. A. Wolff, and the European

delegates were Professor W. Jaeger, Professor F. Laporte, and Mr. F. E. Smith.

Professor S. W. Stratton kindly offered the facilities of the Bureau of Standards for the investigation, and, in his capacity as Treasurer of the International Committee, was able to secure the funds to defray expenses. Towards this object the governing bodies of the American Institute of Electrical Engineers, the National Electric Light Association, the Association of Edison Illuminating Companies, and the Illuminating Engineering Society most generously subscribed 100*l.* each. Some smaller contributions were also received.

The primary object of the meeting was to determine the electromotive force of the Weston normal cell in terms of the international units of resistance and current. At the same time it was necessary to clear up certain outstanding problems on the standard cell and the silver voltameter. Previous to the meeting a great deal of experimental work had been done at each of the four institutions, and the results obtained were compared before deciding on a programme of experimental work.

The European delegates took with them from their own laboratories a considerable quantity of apparatus and chemicals, together with standards of electromotive force, resistance, and mass. The results of the meeting are very valuable, and a full report is in process of preparation.

Another careful research on the silver voltameter has been made during the year by Professor F. Laporte at the Laboratoire Central d'Electricité. Professor Laporte shows that the result obtained in 1908 by Professors Janet, de la Gorce, and himself, is subject to an appreciable error, owing to the use of silver nitrate, now known to be impure. With carefully prepared nitrate, and using the Rayleigh form of voltameter, he obtains 1·11829 milligram per coulomb for the electro-chemical equivalent of silver, the current being measured in terms of the Weston cell as 1·01830 volt at 17° C. and the international ohm as realised at the National Physical Laboratory. The unit of current was, therefore, the same as that used by Smith, Mather, and Lowry in 1908, and the value for the electro-chemical equivalent found by Professor Laporte is in very close agreement with the value 1·11827 obtained by the British investigators.

The General Committee at Winnipeg accepted the recommendation of the Council and the Committee of Section A in favour of the republication of all the Reports of the Electrical Standards Committee. Suitable arrangements for the work have, therefore, been made, and the material is now with the printer, but in consequence of the absence of Mr. F. E. Smith in America, and the work of preparation required, progress has necessarily been slow.

With regard to progress in electrical standardising work at the National Physical Laboratory, the Lorenz apparatus is practically complete, and some preliminary electrical measurements will, it is hoped, be made in October of the present year.

The Ayrton-Jones current balance continues to work most satisfactorily, and small and gradual changes in E.M.F. of Weston cells,

amounting to less than three parts in 100,000 have been detected by its aid.

The results of the investigation on cadmium amalgams at the National Physical Laboratory were incorporated in a paper read before the Physical Society last February. It may be useful to give here the limits of temperature between which various amalgams may be most usefully employed in the Weston normal cell:—

Percentage of cadmium in the amalgam		Lower limit	Upper limit
6	.. ..	Below 0° C.	about $27^\circ{\cdot}7$ C.
7	.. ..	"	" 34·6
8	.. ..	"	" 41·0
9	.. ..	"	" 46·0
10	.. ..	"	" 51·0
11	.. ..	about 0 C.	" 56·0
12	.. ..	" 8·7 C.	" 60·0
12½	.. ..	" 12·1	above 60·0
13	.. ..	" 16·1	" 60·0
14	.. ..	" 24·0	" 60·0
15	.. ..	" 32·5	" 60·0

The degree of reproducibility which is now obtainable with the Weston cell far surpasses what it was five years ago. At the National Physical Laboratory sixty-seven cells were tested in 1909, and of these sixty agreed with the Laboratory standards within one part in ten thousand. What is not understood at present is the occurrence of strange hysteresis effects in a few cells. The E.M.F. of such cells may be normal at first, but changes comparatively rapidly with time. Indeed, a large hysteresis effect in a cell appears to be an indication that the E.M.F. will not remain constant with time, whereas its absence is in general an indication of constancy.

In view of the fact that the republication of the Reports is not yet completed, the Committee recommend that they be reappointed, that Lord Rayleigh be Chairman, and Dr. R. T. Glazebrook Secretary.

APPENDIX.

Order in Council relating to Electrical Standards.

At the Court at Buckingham Palace, January 10, 1910. Present: the King's Most Excellent Majesty in Council.

Whereas by the 'Weights and Measures Act, 1889,' it is, among other things, enacted that the Board of Trade shall from time to time cause such new denominations of standards for the measurement of electricity as appear to them to be required for use in trade to be made and duly verified.

And whereas by Order in Council dated the 23rd day of August, 1894, Her late Majesty Queen Victoria, by virtue of the power vested in Her by the said Act, by and with the advice of Her Privy Council, was pleased to approve the several denominations of standards set forth in the Schedule thereto as new denominations of standards for electrical measurement.

And whereas in the said Schedule the limits of accuracy attainable in the use of the said denominations of standards are stated as follows:—

For the Ohm within one hundredth part of one per cent.
For the Ampère within one tenth part of one per cent.
For the Volt within one tenth part of one per cent.

And whereas, at an International Conference on Electrical Units and Standards held in London in the month of October, 1908, the International Electrical Units corresponding with the said denominations of standards were defined as follows:—

The International Ohm is the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice 14·4521 grammes in mass of a constant cross sectional area and of a length of 106·300 centimetres.

The International Ampère is the unvarying electric current which, when passed through a solution of nitrate of silver in water, deposits silver at the rate of 0·00111800 of a gramme per second.

The International Volt is the electrical pressure which when steadily applied to a conductor whose resistance is one International Ohm will produce a current of one International Ampère.

And whereas it has been made to appear to the Board of Trade to be desirable that the denominations of standards for the measurement of electricity should agree in value with the said International Electrical Units within the said limits of accuracy attainable;

And whereas the denominations of standards made and duly verified in 1894 and set forth in the Schedule to the said Order in Council have been again verified;

And whereas the Board of Trade are advised that the said denominations of standards agree in value with the said International electrical units within the said limits of accuracy attainable, except that in the case of the Ohm the temperature should be 16°·4 C. in place of 15°·4 C. as specified in the Schedule to the said Order in Council;

And whereas it has been made to appear to the Board of Trade that the said denominations of standards should be amended so that the aforesaid exception may be remedied;

Now, therefore, His Majesty, by virtue of the power vested in Him by the said Act, by and with the advice of His Privy Council, is pleased to revoke the said Order in Council dated the 23rd day of August, 1894, and is further pleased to approve the several denominations of standards set out in the Schedule hereto as denominations of standards for the measurement of electricity. ALMERIC FITZROY.

'SCHEDULE ABOVE REFERRED TO.

'I. *Standard of Electrical Resistance.*

'A standard of electrical resistance denominated one Ohm agreeing in value within the limits of accuracy aforesaid with that of the International Ohm and being the resistance between the copper terminals of the instrument marked "Board of Trade Ohm Standard Verified, 1894 and 1909," to the passage of an unvarying electrical current when the

coil of insulated wire forming part of the aforesaid instrument and connected to the aforesaid terminals is in all parts at a temperature of 16°·4 C.

'II. *Standard of Electrical Current.*

'A standard of electrical current denominated one Ampère agreeing in value within the limits of accuracy aforesaid with that of the International Ampère and being the current which is passing in and through the coils of wire forming part of the instrument marked "Board of Trade Ampère Standard Verified, 1894 and 1909," when on reversing the current in the fixed coils the change in the forces acting upon the suspended coil in its sighted position is exactly balanced by the force exerted by gravity in Westminster upon the iridioplatinum weight marked A and forming part of the said instrument.

'III. *Standard of Electrical Pressure.*

'A standard of electrical pressure denominated one Volt agreeing in value within the limits of accuracy aforesaid with that of the International Volt and being one hundredth part of the pressure which when applied between the terminals forming part of the instrument marked "Board of Trade Volt Standard Verified, 1894 and 1909," causes that rotation of the suspended portion of the instrument which is exactly measured by the coincidence of the sighting wire with the image of the fiducial mark A before and after application of the pressure and with that of the fiducial mark B during the application of the pressure, these images being produced by the suspended mirror and observed by means of the eyepiece.

'In the use of the above standards the limits of accuracy attainable are as follows:—

'For the Ohm, within one hundredth part of one per cent.
'For the Ampère, within one tenth part of one per cent.
'For the Volt, within one tenth part of one per cent.

'The coils and instruments referred to in this Schedule are deposited at the Board of Trade Standardising Laboratory, 8 Richmond Terrace, Whitehall, London.'

Establishing a Solar Observatory in Australia.—Report of the Committee, consisting of Sir DAVID GILL (*Chairman*), Dr. W. G. DUFFIELD (*Secretary*), Dr. W. J. S. LOCKYER, Mr. F. MCCLEAN, *and* Professors A. SCHUSTER *and* H. H. TURNER.

DURING the past year the movement for the establishment in Australia of a solar observatory has made considerable progress, the annual upkeep having been promised by the Commonwealth Government provided that a sum of 10,000*l.* be forthcoming from private sources for its erection and equipment.

The Secretary was in Australia during the early part of the year 1909-10, and he has already reported[1] the formation of the Solar

[1] Winnipeg Report, 1909.

Physics Committee of the Australasian Association for the Advancement of Science, as well as the favourable reply from the Minister of Home Affairs of the Fisher Ministry in response to their deputation upon the subject, shortly before the Deakin Ministry came into power.

In order to demonstrate the strong feeling throughout Australia that this work should be undertaken, a public meeting was convened by the Solar Physics Committee in the Melbourne Town Hall on October 26, 1909. Delegates were appointed by the Councils of the Universities of Sydney, Melbourne, Adelaide, and Hobart, the observatories of Melbourne and Adelaide, the Royal Societies of New South Wales, Victoria, and South Australia, and the Astronomical Societies of Sydney and Adelaide. The meeting was presided over by the Earl of Dudley, Governor-General of Australia, who concluded his opening address with the words:—

'It will be little short of a national misfortune if, for the sake of a few thousand pounds, Australia fails to take the place amongst the nations of the world in scientific research for which her geographical position marks her out. The country appears destined by Nature for the work, and it is doubtful whether it can be done anywhere else so well as here. The location of the new station in Australia would mean that three out of the four necessary links in the chain of observatories would be within the Empire, and that all four—the American, the British, the Indian, and the Australian—would be run by English-speaking peoples. It would also show that Australia recognised her responsibilities and her opportunities, and had taken her place amongst the nations of the world, at any rate in the realms of science.'

The following resolution was put to the meeting and carried unanimously: '*That the establishment of a Solar Observatory in Australia is desirable, and that the Federal Government be strongly urged to assume the responsibility of carrying it into effect.*' Sir Thomas Gibson-Carmichael, Governor of Victoria, Sir George Reid, High Commissioner for Australia, Sir John Madden, Chancellor of the Melbourne University, Professors David and Henderson, Mr. Baracchi, Government Astronomer of Victoria, Mr. Hunt, Commonwealth Meteorologist, and others spoke in favour of the establishment of the observatory.

In response to a question asked in the Commonwealth Parliament concerning the Government's intention of undertaking this work, the Prime Minister, Mr. Deakin, replied: '. . . It appears to me that the Commonwealth ought to do its share in this matter. I propose, therefore, to ask my honourable colleagues to place on the Estimates a sum sufficient for the maintenance of such an observatory. If necessary, we may go further, but it is desirable that in the first instance the wealthy men of Australia should have their attention called to the opportunity now presented them for the erection and equipment of an observatory whose results would be valuable to the world at large, and incidentally to Australia. The Commonwealth Government would be prepared to maintain it for the sake of science and Australian meteorology.' November 4, 1909.

Mr. Deakin subsequently stated that the Cabinet had approved of a proposal upon the above lines for submission to Parliament. The

cost of maintenance of a solar observatory at a suitable spot in the interior of the continent was estimated at about 1,500*l.* per annum for the earliest years, 'with probably an expanding outlay as the work developed.'

The Labour Ministry under Mr. Fisher has now returned to power, and it is thought that it will be no less sympathetic than Mr. Deakin's Ministry. Towards the sum of 10,000*l.* that is required for the construction and equipment, about 4,000*l.* has been subscribed in money and apparatus, so that as matters stand at present the sum of 6,000*l.* is alone required to enable the whole world to be linked up by a chain of observatories, and the scheme of International Co-operation in Solar Research to be carried completely into effect.

Seismological Investigations.—Fifteenth Report of the Committee, consisting of Professor H. H. TURNER (*Chairman*), Mr. J. MILNE (*Secretary*), Mr. C. VERNON BOYS, Sir GEORGE DARWIN, Mr. HORACE DARWIN, Major L. DARWIN, Dr. R. T. GLAZEBROOK, Mr. M. H. GRAY, Professor J. W. JUDD, Professor C. G. KNOTT, Professor R. MELDOLA, Mr. R. D. OLDHAM, Professor J. PERRY, Mr. W. E. PLUMMER, Professor J. H. POYNTING, Mr. CLEMENT REID, *and* Mr. NELSON RICHARDSON. (*Drawn up by the Secretary.*)

[PLATES I AND II.]

CONTENTS.

I. *General Notes.*

THE following notes, which have been brought together to form the fifteenth Annual Report of this Committee, refer for the most part to work which is in progress rather than to work which has attained a stage approximating completion.

Your Committee ask to be reappointed with a grant of 60*l.*

Registers.—Since the meeting of last year Circulars Nos. 20 and 21 have been issued. They refer to observations made at Shide, Kew, Bidston, Edinburgh, Paisley, Eskdalemuir, Haslemere, West Bromwich, Stonyhurst, San Fernando (Spain), Valetta, Beirut, Ponta Delgada, Cape of Good Hope, Mauritius, Cairo, Bombay, Kodaikanal, Alipore, Colombo, Irkutsk, Tokio, Batavia, Toronto, Victoria, Baltimore, Trinidad, Chacarita and Pilar (Argentine), Honolulu, Perth, Sydney, and Christchurch.

Visitors.—Although many visitors have called at Shide Observatory merely to satisfy curiosity, there have been a number who have visited this station with the express object of obtaining information which they could turn to practical account. The following gentlemen spent two days at Shide to study the routine of a seismological observatory: N. K. Fennimore (St. Helena), C. E. Pain (Seychelles), F. Marx (Ascension), J. G. Meats (St. Vincent, Cape Verde), H. G. Thomas (Cocos), C. E. Holmes (Fernando Norhona), R. Rankine (Fiji), J. J. Shaw (West Bromwich), F. Ryan (Electra House, London), the Rev. A. L. Cortie, S.J. (Stonyhurst). Other visitors practically interested in seismology were F. E. Norris (Guildford), G. W. Walker (Eskdalemuir), W. E. Cooke (Perth), Major A. E. Galbraith, R.E. (Osborne), Lieut. W. A. Moore, R.A. (Freshwater), Professor F. G. Baily (Edinburgh), Professor H. H. Turner (Oxford), and M. H. Gray (Abbey Wood). W. R. Hearn (Consul-General, San Francisco) and Professor E. F. Pinto Basto (Coimbra) both gave assistance towards obtaining material for a catalogue of destructive earthquakes. In addition to these individual visitors, Shide was visited by several parties, the Lymington Natural Science Society, some twenty visitors from Rouen, Professor Vèlain with his assistants and a number of students from the Sorbonne. These latter took a keen interest in everything they saw, and were particularly struck with the method followed by the British Association in making seismological observations as contrasted with the method which is now in process of extension in their own country. From Japan we were visited by Count Otani Kodzui and two of his assistants, who had just returned from Central Asia, where incidentally they had observed large earthquakes. Their records were compared with those obtained at European and other stations. Professor H. Nakano very kindly offered to give us such assistance as he was able in obtaining more complete records from Japan. I may add that for a considerable time past we have been indebted to Mr. J. Rippon, of the West India Cable Company, for registers of earthquakes which have occurred in Jamaica.

II. *New Stations.*

Installations are now in working order at West Bromwich and Guildford, and shortly we expect to receive a large series of records which have been made from Melbourne. Through the kind co-operation of the Eastern, Eastern Extension and Pacific Telegraph Company, instruments will very shortly be established at St. Vincent (Cape Verde Islands), Ascension, St. Helena, Seychelles, Cocos and Fanning Islands. Other cable companies are considering the advisability of establishing instruments at certain of their stations, whilst, largely in consequence of the interest taken in seismological observations by Sir Everard im Thurn, an instrument will very shortly be shipped to Fiji. Inquiries have also been received respecting the installation of seismographs in several other colonies. New recording instruments in which the paper moves at the rate of 240 mm. per hour have been adopted at the Royal Observatory, Edinburgh; by the Geographical Society, Lima, Peru; and at

Stonyhurst College, near Blackburn. New instruments with quickly moving record-receiving surfaces have been sent to the Instituto y Observatorio de Marina, San Fernando, Spain; the Rio Tinto Company, Limited; Huelva, Spain; Cardiff; and Adelaide.

West Bromwich, Hill Top.—The instrument established by Mr. Shaw at this station has two pendulums: A, with the boom-point to the east and weight to the west; B, with boom-point to the south and weight to the north. These are suspended from the walls of a cellar excavated in hard gravel. In descending order the strata beneath are 105 feet of clay and red sand, 108 feet of clay, clunch, and coal, 60 feet of white rock, 63 feet of rock binds, and 31 feet of coal. The weights are 100 kilos. each. Period 16 seconds. The weight on A is 36 inches from the boom-point, whereas the weight of B is 54 inches from the boom-point.

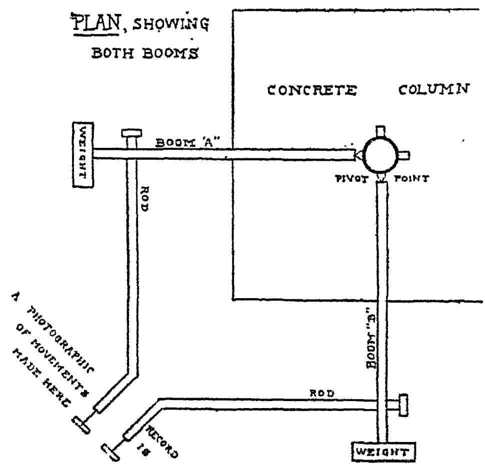


FIG. 1.

Both booms are fitted with multiplying levers (ratio, 20: 1) giving a total sensibility for A 0″·1 tilt=1 mm. amplitude; and for B 0″·15 tilt=1 mm. amplitude.

The records are taken on smoked paper travelling five inches per hour.

The time is recorded by electric signal each minute, and the governing clock compared with Greenwich daily. Average variation about one second per diem.

Guildford, Woodbridge Hill.—This instrument was designed and put up by Mr. F. E. Norris. The mast rises 4½ feet above the top of a concrete column, which is sunk 5 feet in London clay. There is a north boom (A) and a west boom (B) recording without multiplying levers. Length of boom, 3 feet; weight at outer end, 100 lb. 1 mm. displacement=1″·88 arc.

Instruments in Jamaica (for local shocks).

1. *Chapelton (M. Maxwell Hall).*—A duplex-pendulum seismometer. Heavy weight, about 30 lb. Multiplication about 10 for horizontal movements only. Records on top upon a smoked-glass plate.

2. *Kingston (Brennan).*—Made after the pattern of Gray, of Glasgow. A heavy weight ring about 9 inches diameter, 25 lb. weight, acts as a pendulum, with 'dampers' to prevent continued oscillation termed 'friction pointers.' Multiplication about 12. Records upon a smoked-glass plate below, same as described in Milne's book on earthquakes. All enclosed in a case free from wind currents. Length of suspension about 5 feet.

Verbeck's Ball and Plate Seismometer.—Described in Milne's book. Consists of two plates of glass 2 feet by 18 inches by ½ inch, about 25 lb. each, separated by three ¾-inch steel bars horizontally fixed. Registers on the top surface of top plate. This will give the *actual* horizontal movement of the ground, and is intended for large earthquakes. Can register a movement of about 2 or 3 inches. Fixed firmly to the ground and protected from air currents.

III. *Distribution of Earthquakes in* 1909.

The dash-dot lines on the accompanying chart (Plate I.) are parallel to the axes of districts from which large earthquakes have originated. It will be observed that they follow the principal ridges and troughs on the earth's surface, but not necessarily to their extremities.

In the Pacific the lines P, E_1, A_1, A_2, B, D_1, and D_2 follow the lines of troughs, while the remaining lines in the same ocean follow ridges. In the Atlantic the eastern portion of C_1 and H are ridge lines, whilst the western portion of C_1 is the portion of a trough.

In Africa K_8 is a ridge, whilst O and its northerly continuation to the Jordan depression is partly a trough.

In the Indian Ocean part of G_1 and G_2 are parallel ridge lines, whilst F_3, F_2, M_1, and R are troughs.

The lines in Europe and Asia follow ridges; K_1 is the Tian Shan-Altai system, which is continued to the north-east by the Stanovoi-Yabolonoi ranges. From this north-eastern extension, however, but few earthquakes originate. K_2 is the Kwen Lun system, which ends abruptly at the great plain of China or turns at right angles near the great bend of the Hoango Ho and follows the fold of the Khingan Mountains to the northern bend of the Amur. K_7, K_4, K_3 is the Alpine, Balkan, Caucasian, Himalayan system, which turns sharply round the eastern bend of the Brahmaputra, and as the Arakan Yoma range runs down to Cape Negrais, to be continued by stepping stones, the Andamans and Nicobars, to join the Sumatra-Java volcanic ridge.

The number of earthquakes which have originated from each of these districts in 1909 was A, 4; B, 3; C, 0; D, 6; E, 18; F, 24; G, 3; H, 2; J, 0; K, 25; L, 0; M, 13; N, 0; O, 0; P, 0. The total

number of earthquakes since 1899 from these same districts, therefore, becomes A 40; B, 55; C, 30; D, 28; E, 133; F, 175; G, 26; H, 35; I, 5; J, 5; K, 141; L, 2; M, 86 (this includes small disturbances); O, 1; P, 0.

The most pronounced megaseismic activity is at the present time along a band running from the south extremity of the Philippines and Java in an east-south-east direction towards the middle of the Pacific. In the islands which stud this band with their intervening troughs we see the outcrops of mountain ranges with Himalayan proportions. It suggests a continent in the making.

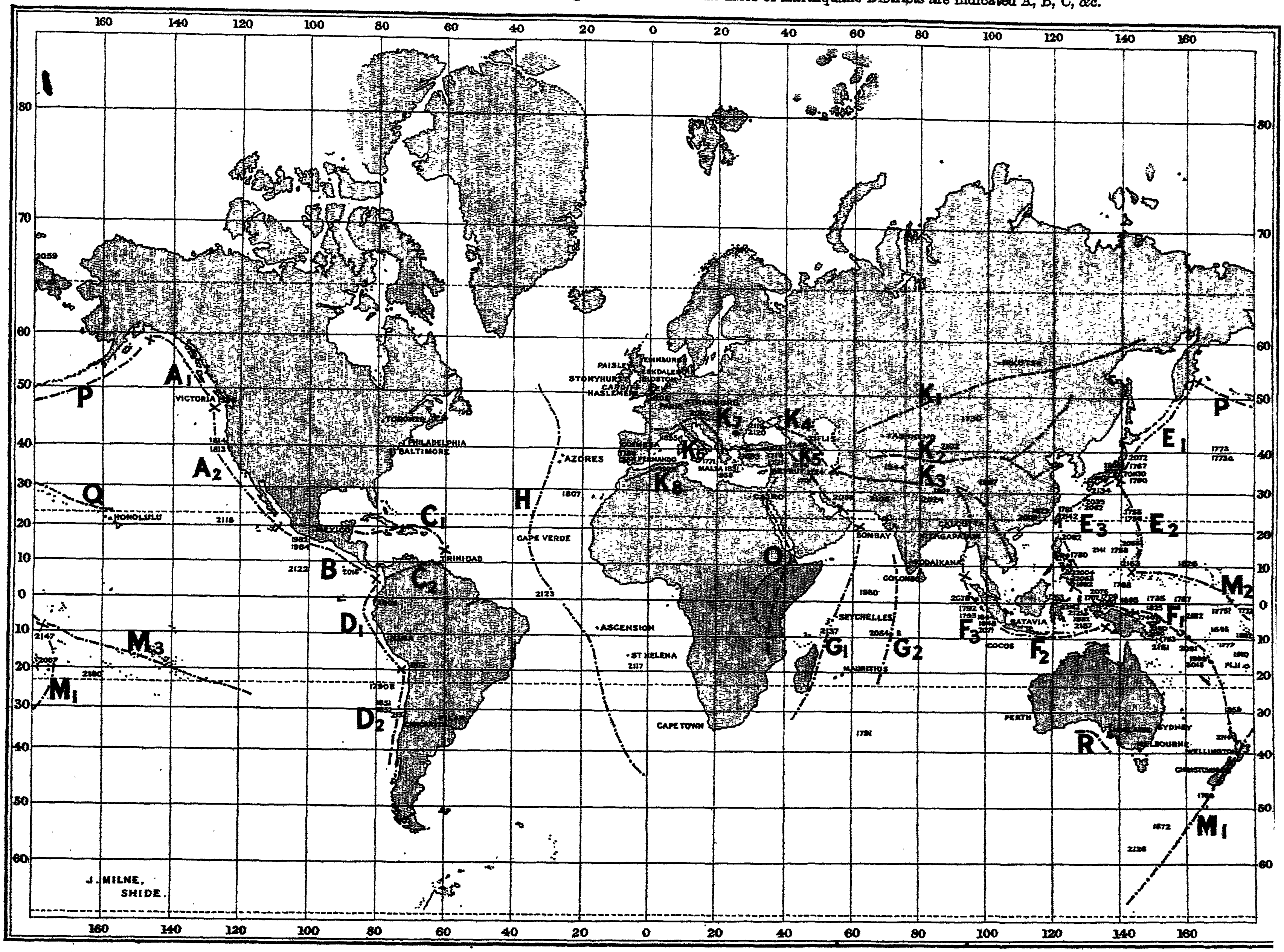
IV. *A New Departure in Seismology.*

In the British Association Report, 1908, p. 64, I showed that after the earthquake of January 14, 1907, which devastated Kingston, Jamaica, 51 of the after-shocks were recorded by the British Association type of instrument at several stations in Great Britain. The time taken for these to travel from Jamaica to Great Britain, a distance of 67°, was in all cases practically 43 minutes. I am not aware that any one of these 51 shocks was recorded by other types of instruments either in Britain or Europe. Previously to this, however, very large shocks had been recorded as thickenings of traces near to the antipodes of their origin, but this was the first time that small after-shocks had been noted at places far removed from their epicentral areas. We have here not only an indication of the high degree of sensibility possessed by a certain type of instrument, but a suggestion that a new field for exploitation had been discovered. Observations corresponding to those made on the shocks from Jamaica have been frequently repeated, with the result that the registers from stations possessing different types of instruments show considerable variation in the number of records which they yield. For example, between July 1 and December 31, 1909, we find that in the Isle of Wight 279 earthquakes were noted. These are assumed to be of true seismic origin, either because each finds a corresponding record at several other stations, or that they were noted at times when we should expect the surviving efforts of large earthquakes to arrive in Great Britain. During this period, at Hamburg, Strassburg, and Laibach, where other types of instruments are in use, the number of records were respectively 123, 64, and 42. At these latter stations, like many others in the world, we find either instruments recording on smoked paper or instruments which recorded photographically. In the former the writing pointers are connected with the bob of a pendulum by a system of levers which gives a high multiplication, whilst with the instruments which record photographically the source of light is at a considerable distance from the record-receiving surface. With the first type of instrument a slackness in joints, together with elasticity and inertia of the levers, results in a loss of motion. Where the multiplication is high the makers of these instruments tell us that this amounts to five per cent. This means that no record whatever can be obtained until a certain amplitude of motion

British Association, 80th Report, Sheffield, 1910.] [PLATE I.

The Large Earthquakes of 1909.

Origins for 1909 are indicated by their B.A. Shide Register Number. The Axes of Earthquake Districts are indicated A, B, C, &c.



Illustrating the Report on Seismological Investigations.

has been reached. This accounts for the fact which has so frequently been confirmed by my own experiences that this type of instrument fails to record very small movements. Why the second type of instrument carries the same objection is not so clear. We frequently notice that the traces from these instruments are not only broad, but they are wanting in definition. Small movements may possibly be lost in the ill-defined edges of the trace.

On December 28, 1908, Messina and Regio were ruined. Eight of the after-shocks reached the Isle of Wight, but only two of these seem to have been recorded at Laibach, Göttingen, and Hamburg, which are nearer to the origin than the Isle of Wight.

A similar story is told in all the registers published since 1907. Earth messages appear to be passing beneath observatories all over the world, but their existence is not recognised, because the instruments generally used are not capable of recording the same. To exploit this new department in seismology old types of instruments will have to be improved or new ones adopted.

V. *Changes in Level accompanying certain Earthquakes.*

All geologists are familiar with the enormous mass displacements which have accompanied very large earthquakes, particularly in the vicinity of their origin. It does not, however, appear to have been recognised that small changes in level may sometimes be detected at great distances from the same. Evidences of such changes are occasionally to be seen in the records obtained from horizontal pendulums. As an illustration of this I will refer to the earthquake of January 22, 1910, which had its origin to the north of Iceland. With the maximum motion of this disturbance at Shide, in the Isle of Wight, the booms of five horizontal pendulums were suddenly displaced from their normal position. Those oriented east and west were swung to the north, whilst those at right angles to the west. Pendulums in rooms 80 yards apart were displaced similarly. In their new positions they were all free to swing. The displacement took place at 8 A.M., but at 12.45 they crept back somewhat intermittently towards their original zero. This they reached at 4 P.M. The behaviour of pendulums at Bidston and West Bromwich suggested a displacement similar to that at Shide. In the seismograms which I have accumulated during the last fifteen years I find many repetitions of a similar phenomenon.

VI. *Changes in Level due to Tidal Influence.*

Towards the end of last year it occurred to Professor Milne that the conditions under which the earthquake records were made at Bidston might be utilised to determine the amount of deformation of the earth's surface due to the accumulation and removal of a heavy load of tidal water.

A few years ago, in the basement of the Victoria Club at Ryde, Professor Milne made some observations with this in view. Contrary to expectations, it was found that when the tide rose the strand rose

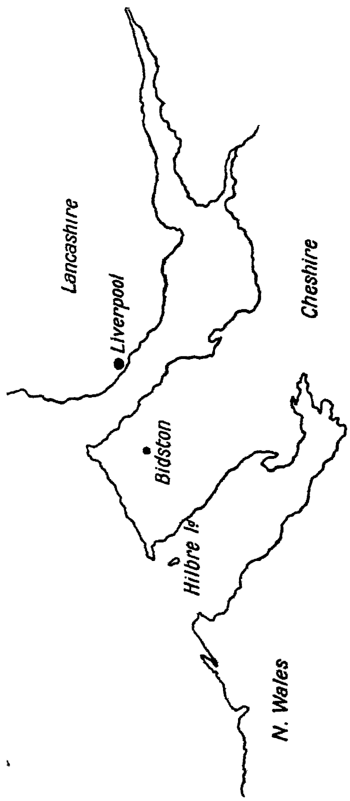
also. This was attributed to the banking up of drainage from the land and the consequent bulging up of the same. It was, however, pointed out by Sir George Darwin that the greater quantity of water in the English Channel might more than counterbalance the effect of the smaller volume in the Solent.

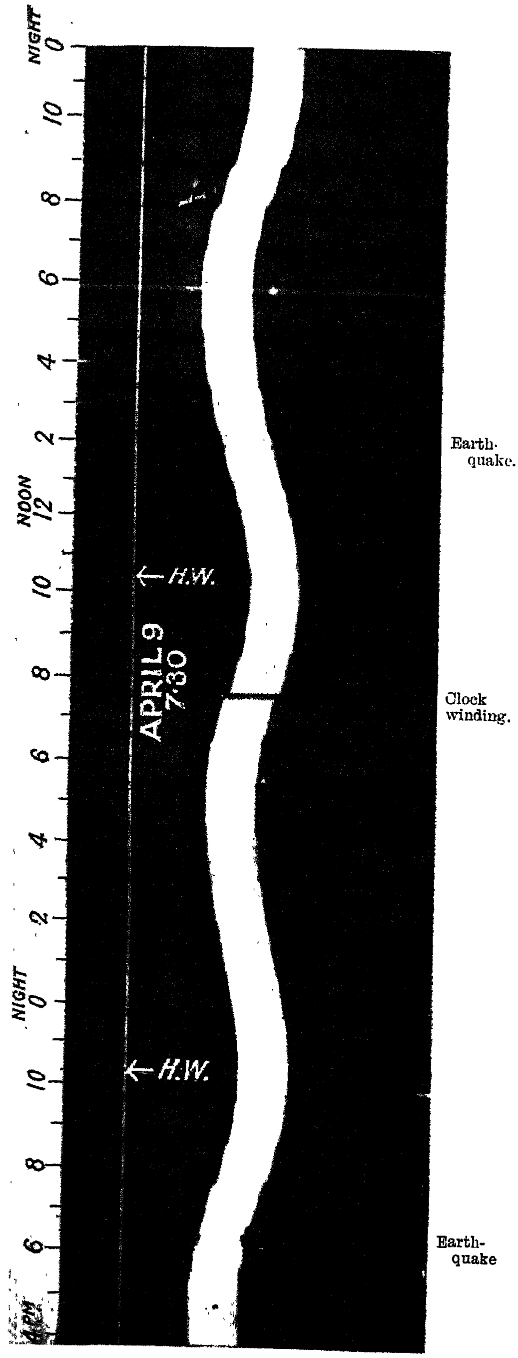
In the Mersey, as shown by the tide gauges on the Liverpool Landing Stage, the variation in the height of the tide can considerably exceed 10 feet, and in the Dee, at Hilbre Island, the oscillation is practically the same. The difference in the time of high water at these two stations is about half an hour. Consequently, as a glance at the rough map of the coast-line will show, there is a tendency for the load to balance on the east and west sides, while on the north and south, apparently, the difference would be most marked. In these circumstances it is a little difficult to determine what would be the most appropriate azimuth to mount the pendulum, but as the boom in the original seismometer was placed north and south, in the new instrument the direction was made east and west. The seismometer can, however, be turned through any angle if it be felt desirable to continue the investigations.

The instrument used was designed by Professor Milne and his assistant, Mr. S. Hirota. All the observations were made and discussed by Mr. W. E. Plummer, Director of the Bidston Observatory.

The boom differs in some essential particulars from the type ordinarily used in the Milne seismometer. It is divided into two parts: one, nearer to the stand, consists of a stout brass rod, carrying a weight of about seven pounds. At the extremity of this rod, which is only about 30 inches in length, is placed a light magnifying style, independently carried, and attached to the boom proper by means of a magnetised needle, capable of moving between a slender iron fork. The sensitiveness of the instrument can be increased at will by reducing the distance between the pivot on which the magnifying style works and the end of the boom. In the original construction the multiplying arm was 10 inches long, rotating about a centre 1 inch from the end of the boom, consequently the displacement was magnified ten times. The arrangements for photographing the movement were of the ordinary character. The sensitised paper was paid out at the rate of 5 millimetres an hour, so as to make the small amplitude of the oscillation apparent. The tidal displacements were sufficiently noticeable, and the accordance with the time of high water was satisfactory. To increase the sensitiveness of the instrument so as to make the motion more distinct and easily measured, and to remove any danger of the needle failing to engage the steel forks, it was felt desirable to adopt a different method of connection. With this view, Professor Milne suggested that the magnetised needle should be removed and the multiplying piece mounted as a bifilar pendulum, an arrangement which allowed the centre of motion to be brought much nearer to the end of the boom and gave a multiplication of about forty times. The method of photographing the point of light was changed, and a thin strip of black paper substituted. This apparatus has been in use since March 1910, and generally works

Map showing position of Tidal Water round Observatory.





Deflections recorded at Bidston due to Tidal Load.

Illustrating the Report on Seismological Investigations.

satisfactorily. The diagram (Plate II.) shows the character of the photographs that are now being taken. The instrument is not well adapted for the record of earthquake waves, but two small tremors are shown; the second one is not to be found on the ordinary earthquake film.

Some difficulties have been introduced by the greater sensitiveness, and some were made more apparent, but these will probably disappear with greater experience. One difficulty was to determine the linear displacement of the boom due to an angular tilt of the instrument, for the smallest angular motion which it was possible to make with accuracy moved the multiplying style off the scale. It seemed necessary to reduce the sensitiveness by a known factor—that is, by increasing the distance between the supports of the bifilar portion. There are objections to this plan, and up to the present the results have been left in the form of the actual measured displacement. Another difficulty arose from a long slow movement of a very minute order in one direction, probably masked in the less sensitive instrument, but now distinctly noticeable in a continued series of observations. To explain this creeping it may be mentioned that the whole seismometer is mounted on a slate slab on the top of a drain-pipe, two feet in diameter. This form of stand was preferred by Professor Milne, because it avoided the drying of mortar or cement, which, in a brick-built pier, would take a very considerable time. The observed creeping may be due to some motion of the stand or of the hill on which the Observatory is built, akin to the annual variation in the azimuthal error of the transit instrument. While the instrument has been in use the temperature has been increasing. Observations in the second half of the year may clear up this point.

It must not, however, be overlooked that one possible cause for this creeping may be found in the seasonal shift in the direction of the north-south barometrical gradient, accompanied by a seasonal change in the mean sea-level. In summer time the region of high barometrical pressure lies to the north of Great Britain, whilst in winter it lies considerably to the south.

The amplitudes on the diagrams seem sufficiently large to warrant an attempt to determine the tidal constants by means of harmonic analysis in the same way that the records of a tidal gauge are used. It may be said here that it was hoped originally to determine from the residuals between the computed and observed curves the direct effect of the moon's tide-generating force. At the present moment such an inquiry is no doubt rendered difficult owing to the slow creeping of the pendulum towards the north. The problem resembles that of trying to find the height of the tides from readings on a scale that is continually sinking into the ground, and at a rate which cannot be determined and which may not be uniform. There are also other practical difficulties connected with the winding of the clock, attending to the illumination, &c. It is by no means certain that after a disturbance the boom returns to the position originally occupied with no greater error than the small quantity sought. The discussion of the results, so far as they have gone, is useful as emphasising these difficulties, and with that view they are printed here. The observations from April 14 to April 28 seemed as free from objection as any that have been made, and as a

first attempt it was arranged to derive the several tides in the manner described by Professor Sir G. H. Darwin. Clearly, if the main tides could not be recognised, it was hopeless to look for more recondite effects. There is a slight want of definiteness in the edge of the photograph; but this defect has been to some extent removed, it is hoped, by measuring both sides and using the mean. The curve was read off to a tenth of a millimetre, and that unit has been used throughout.

The results of the harmonic analysis are given in the following table. About these Sir George Darwin writes as follows: 'Since the oscillations of the pendulum are due to the weight of sea-water, it seems best to compare them with the tidal constants, as derived from ten years of observation at Hilbre Island.[1] This place being near the mouth of the Dee, seems to afford a better means of comparison than does Liverpool. The constants for Liverpool, however, differ but slightly from those at Hilbre Island. It is further desirable to compare the results with those derived from the equilibrium theory of tides for a place in lat. 53° 24′, approximately that of Bidston. I gave in Table E of the Report on Tides to the British Association for 1883 (' Scientific Papers,' vol. i., p. 25) a theoretical scale of importance of the several tides expressed in terms of the principal lunar semidiurnal tide M_2 as unity. But this table takes no account of the latitude of the place of observation, merely giving the relative importance of the several " coefficients.' What we require is to know what would be the deflections of the pendulum at Bidston if it were erected on an absolutely unyielding soil, and were only affected by the tide-generating forces due to moon and sun. The values given in that table for the semidiurnal tides may be quoted directly therefrom, and give the results in terms of M_2 as unity. But to reduce the diurnal tides to the same measure for this latitude, we must multiply the tabular values by $\sin 2\lambda \sec^2\lambda$, where λ is latitude. In this way we obtain a scale of relative importance for the lunisolar tide-generating force at Bidston.

	$\frac{1}{10}$ mm.	Hilbre Island	Tide-generating force at Bidston
Lunar semidiurnal M_2 .	$H = 17{\cdot}52$	9·758 ft.	1·000
	$\kappa = 318°$	319°	0°
Solar semidiurnal S_2 .	$H = 7{\cdot}45$	3·128 ft.	0·465
	$\kappa = 327°$	3°	0°
Lunisolar semidiurnal K_2 .	$H = 2{\cdot}03$	0·890 ft.	0·127
	$\kappa = 327°$	358°	0°
Lunisolar diurnal K_1 .	$H = 5{\cdot}64$	0·391	1·572
	$\kappa = 346°$	188°	0°
Solar diurnal P . .	$H = 1{\cdot}88$	0·146	0·520
	$\kappa = 346°$	174°	0°
Lunar diurnal O . .	$H = 1{\cdot}86$	0·370	1·118
	$\kappa = 237°$	41°	0°

Since the series of observations only extended over a fortnight, it was necessary to *assume* that the phase of K_2 was the same as that of S_2, and the amplitude about $\frac{3}{11}$ths. Similarly the phase of P is assumed to be identical with that of K_1, and the amplitude one-third. Hence in

[1] See Baird and Darwin, *Proc. Roy. Soc.* vol. xxxix. (1885), p. 196, col. 33.

the case of the pendulum there are really only four independent evaluations, and the values of K_2 and of P might have been omitted as far as concerns the provision of a means of comparison between the pendulum and the tide.

'A fortnight is much too short a period of observation to afford trustworthy values for the deflections of the pendulum, and therefore we should not place implicit reliance on the exact numerical values obtained.

'The phase of M_2 for the pendulum is virtually identical with that of the tide, but this exactness of coincidenie is probably to some extent accidental. The high tide, so to say, for the solar tide S_2, differs in phase from that of the water by 36° or 1h. 12m., and the amplitude is considerably greater relatively to M_2 than is the corresponding ratio for the sea.

'The phases of the diurnal sea-tides at Hilbre Island are very abnormal, for whereas it might have been expected that they should all come out nearly the same, the phases of K_1 and O differ by 147°. The result is, however, derived from so many years of observation that it is certainly correct and is, moreover, confirmed by the tidal constants for Liverpool. In the case of the pendulum we observe a similar abnormality, for the phases of K_1 and O differ by 109°. It is, however, remarkable that these tides are almost inverted with reference to the sea-tides. One may conjecture that there are perhaps nodal lines for these tides at some short distance out to sea, and that the bulk of the sea which produces the flexure is in the opposite phase from that which gives the visible tide at Hilbre Island and Liverpool. The amplitudes of K_1 and O are also very discordant, both in absolute amount and between themselves. In the sea K_1 and O have nearly the same amplitude, but with the pendulum that of K_1 is three times as great as that of O. This would result if the supposed node of K_1 were nearer the shore than that for O, because if this were so there would be a larger weight of water, oscillating in a phase opposite to that of the sea in shore, to produce flexure in the case of K_1 than in that of O. However, the series is much too short to justify any confidence in such conjectures.

'The last column gives the relative importance of the tide-generating forces for the several tides, and it will be seen that the force for K_1 is much larger and that for O somewhat larger than that for M_2. We see that both in the sea and in the case of the pendulum there is an enormous reduction of amplitude for diurnal tides as compared with the semidiurnal ones, but the reduction is markedly less for the pendulum. If these values should be confirmed, we may perhaps suspect that the direct lunisolar tide-generating force is rendering itself evident in the K_1 tide, and such a conjecture would accord with the phase of K_1 approaching 360° without the intervention of the nodal line at sea suggested above. However, as already pointed out, it is too soon to draw any conclusions with confidence.'

Whatever may have yet to come from this new departure in observations bearing upon Earth Physics, the work already accomplished is suggestive of certain conclusions.

We see that an observatory near to a shore line, in consequence of

the diurnal tilting to which it may be subjected, is unsuitable for certain investigations. This, however, was pointed out by Sir George Darwin in his Report to the British Association in 1882. The discussion suggests precautions in the determination of the nadir at an observatory on the sea-coast, and probably the deepest mine in central Britain is still unsuitable as a place in which to measure the effects of lunar gravitation.

The deflections accompanying tidal loads observed at Bidston indicate a relationship between the yielding of areas represented by rocks and other materials and loads which are fairly well measureable.

These deflections which accompany a 10-foot tide amount at Bidston to approximately $0''\cdot2$. This yielding may be truly elastic, or it may possibly be partly due to the sagging of a surface like that of a raft under the influence of load. This latter idea falls in line with seismological observations, which show day after day that the large waves of earthquakes, whether passing beneath the alluvial plains of Siberia or beneath the crystalline rocks of North America, do so at a uniform speed. Seismology suggests that we live on a congealed surface, which, whether it is thick or thin, light or dense, apparently responds in a uniform manner to undulations which pass beneath it.

VII. *Megaseismic Activity and Rest.*

From historical records it has been shown that there are reasons for supposing that when there has been marked seismic activity in one portion of the world there has been a corresponding activity in some other part (see this Report, Section VIII., and also British Association Report, 1909, pp. 56-58). Although the records on which this conclusion is based only refer to disturbances which have affected land areas and seaboards, it suggests that periods of marked seismic activity are governed by general conditions. We now possess a second register, collected by stations which have co-operated with British Association stations during the last eleven years, which refer to reliefs in seismic strain in all portions of the globe. These I have divided into two classes. First, those which have only been recorded in a single hemisphere; and, second, those which have been recorded in the whole world. To the latter, which crossed an equator, I have given an intensity twice that of those which only disturbed instruments in a hemisphere. Earthquakes which have only been recorded throughout a single continent, no matter how much damage they may have caused, have been omitted. When these two classes are taken *en bloc* and arranged chronologically, it is at once seen that they have occurred in groups, and to each of these groups a value can be given dependent upon the number of shocks it contains and their relative intensities. From centre to centre of each group there are intervals, which usually vary between 10 and 30 days. An interval of 20 days is common, but it rarely reaches 40 days. On the accompanying diagram (see fig. 2) I have plotted the average intensities or values of groups which have been followed by 8, 9, 10, to 34 days of rest. For example, groups with an average intensity of 4·5 were followed by 10 days of rest, whilst groups with intensities of 5·4 have

a rest period of 20 days. The mean line through these various determinations indicates that activity and rest are directly proportional. After marked efforts to bring about adjustments in the crust of our earth there are long periods of quiescence and *vice versa*. A definite time-interval is required to bring about a condition for hypogenic activity.

VIII. *A Catalogue of Large Earthquakes.*

In the British Association Report for 1908 I drew attention to the fact that existing catalogues of earthquakes consisted of materials extremely heterogeneous in their character. Earthquakes which had only shaken a few square miles were included with those which might have shaken the whole world. Further than this the heterogeneity varied

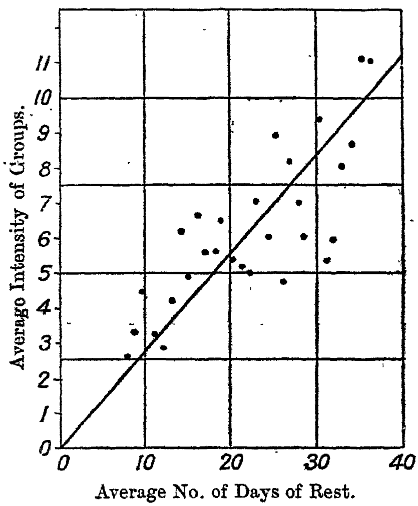


Fig. 2.

in different historical periods. Ancient records only referred to large earthquakes, while, as we approach modern times, this type of disturbance was eclipsed by numerous entries relating to tremors which had only a local significance. If we take this as a fact we see in it an explanation why the numerous analyses of earthquake statistics have failed to reveal any striking results respecting the distribution of earthquakes either in regard to space or time.

To obtain materials which might throw light upon seismic frequency and periodicity, it would be necessary to draw up lists for districts and one for the world from which seismic trivialities were so far as possible excluded. With this object in view, I have made certain progress with a catalogue which only refers to earthquakes which have been accompanied by destruction, or by changes of the earth's surface, or which have extended over large areas. In many instances these disturbances

have resulted in adjustments in the earth's crust of geological importance. Taken in groups they indicate marked periods in the relief of seismic strain.

As an incentive to continue this new type of register, although in 1908 but a small portion of it had been completed, I called attention to the fact that it showed:—

First, that about 1650 there had been a period of marked seismic and volcanic activity in the world.

Second, that although the periods of seismic activity in Italy and Japan were each separated by irregular intervals of time, the years in which there had been marked activity in one of these countries closely corresponded with the years when there had been marked activity in the other. Should further analyses confirm this conclusion, the suggestion is that the relief of seismic strain in one part of the world brings about relief in some other part, or that relief is governed by some general internal or external agency.

The first entry in the catalogue is A.D. 1, and they are continued to A.D. 1900. This portion of the catalogue, which I propose to issue as Part I., will contain about four thousand entries.

I recognise its incompleteness, and trust that the *lacunæ* will shortly be filled up and brought together as a supplement.

When examining this catalogue it must be remembered that it only refers to disturbances which have originated on land surfaces and along seaboards. Further, it must be borne in mind that the historical records of different countries extend over very different periods of time.

The sources from which materials have been drawn are briefly as follow:—

Well-known catalogues like those of Mallet, Perry, and Fuchs have formed a foundation. Next came Japanese catalogues of earthquakes, together with abstracts from records published in China; in these much information is given not obtainable elsewhere. The translations of the latter made by Mr. S. Hirota and Professor E. H. Parker were particularly difficult. In the former of these (see Report 1908) certain slight errors have been found in the materials from which the translations were made. For dates between A.D. 46 and A.D. 194 one or two days should be added, while for dates between A.D. 200 and A.D. 1590 three to ten days should be subtracted. The resulting dates are for the most part those on which earthquakes were notified, and not necessarily those on which they occurred. Numerous lists and monographs on the earthquakes of particular countries have been translated. Three of these accompany this Report. Many documents were obtained from various parts of the world where Great Britain is represented, by the kind co-operation of the Foreign, Colonial, and India Offices. Much time was spent, but, I regret to say, not very profitably, in examining the files of our more important newspapers and periodicals. Better results came from foreign journals and the publications of learned societies. These and other references to sources of information will be detailed in the catalogue.

IX. *Catalogue of Destructive Earthquakes in the Russian Empire.* By MUSHKETOFF and ORLOFF.[1]

Abstracted by Mr. W. A. TAYLOR.

In the original catalogue we find 2,574 entries. From these the following have been abstracted as representing earthquakes of sufficient intensity to have caused destruction.

In many instances the dates for earthquakes which occurred in Chinese territory do not agree with those given by Omori, Hirota, and Parker. An alternative date is marked O. For registers prepared by these three writers see vol. xxix. of the Reports of the Imperial Earthquake Investigation Committee of Japan in Chinese idiographs. Reports of the British Association, 1908, p. 82, and 1909, p. 62. For Chinese lists we have also the 'Catalogue Général des Tremblements de Terre,' &c., presented to the Académie des Sciences by Ed. Biot in 1839, and the recent work by the late Le R. P. Pierre Hoang (see 'Variétés Sinologiques,' No. 28, published by the Mission Catholique, Shanghai, 1909). Dates from the latter are marked H. In many instances the Chinese dates may not refer to the time of an earthquake, but to the time at which it was notified in Pekin or some other city.

I = Earthquakes which have produced slight damage.

II = Earthquakes which have destroyed a few buildings.

III = Earthquakes accompanied by widespread destruction.

W.B. refers to dates according to the tables of W. Bramsen, 'Trans. Asiatic Society of Japan,' vol. xxxvii. Names of Provinces are in parentheses. Places of greatest destruction are in italics.

A.D.		
341		Armenia. I
715		Isnik-Membeji in Armenia, Constantinople. III
775		Mozan and Daralagoz, Siyunik Prov. III
803		Khogot Mountains. II
869		Town of Dvin (Tovin)? III
893		Town of Dvin. III
894		Environs of Erivan. III
989		Greece, Thrace, Byzantine Province, Constantinople. II
995		Armenia, Towns of *Chapajar, Alhakh and Amit.* III
1000	Mar. 29.	Throughout the known world. III
1045		*Erzingan*, Ami and Ekeghiaz Prov. III
1091		Edessa and *Antioch.* III
1111		Van in Armenia. II
1114	Mar. 12.	Samosata, Ghizn-Mansur, Khesun, Marash, Kaben and Sis. III
1124		Khorassan. III
1131		Ani in Armenia. II
1139		Ganja (Elisavetpol), Kapassi-dagh. III
1143	April	Tangut country in Tibet. II
1156	Oct. 26. for 14 months.	Syria, between Aleppo and Malatieh. III
1168		Erzingan. III
1170		Kief. III

[1] *Memoirs of the Imperial Russian Geographical Society*, vol. xxvi., St. Petersburg, 1893.

A.D.		
1196	May 3 or 4.	(1198 according to Likosten and Frigius). Poland, the *Erzgebirge* and the greater part of Germany. II
1219	Jan. 11.	Mshkavank in Armenia. I
1230	May 3.	Vladimir, Kief, Pereyaslavl, Novgorod and environs of Rostof, Suzdal and Vladimir. I
1268		Erzingan. III
1283		Mtsket in Caucasus, II
1287	May.	Erzingan. II
1308		Karabagh in Caucasus. II
1319		Ararat Prov. and Ani in Armenia. III
1348	Jan. 25.	Hungary, Tyrol, S. Italy, *Rome*, *Venice*, *Bâle*, Carinthia, Poland and Germany. I
1363		Mush in Armenia. II
1374	Dec. 8.	Erzingan. II
1378	April 10.	Ninghsia, Shanhan (Kansu), China. II (Hoang, April 30)
1440	Oct. 26.	Fortress Chuanglang in Lan-chou-fu, Shanhan (Kansu). II (Omori has Liang. There is a Lanchou-fu and a Lianchou in Kansu). (Chuanglang T. of Liangchoufu).
1443	June 5.	Bohemia, Silesia, Poland, *Hungary*. I
1458		Erzingan. III
1467	June 9.	Hsuanhua-fu (Chi-li), Tatung-fu (Shansi), especially *Peiyuan and Shochou.* (W.B. June 27.)
1474	Oct. 27.	Hoching (Yunnan). II
1474	Dec. 11.	Lingchou (Shansi). II (Omori has an earthquake on November 24 and December 11 at Lingchou in Ninghsia-fu) (Kansu).
1477	Mar. 19.	Ling-tao in Kungchang-fu, Shanhan (Kansu). II
1477	May 13.	Liang-chou-fu, Yulin-fu, Kan-chou-fu and Ninghsia-fu in Shanhan (Kansu), Yichou-fu (Shantung). II
1478	Aug.	Fort. Yangching (Sze-chuan). II (O. Chentu).
1481	Mar. 10.	Nanking, Fengyang-fu, Huaian-fu, Yangchou-fu, Hochiu in Chang-nan (*sic* Kiangsu and Anhui ?), Yangchou-fu in Shantung and in Honan. I
1482		Erzingan. III
1485	May 26.	Tsunhuachou Shintian-fu (Chi-li). II
1488	Sept. 28.	Hanchou and Mouchou in *Huangtai* (Sze-chuan). II
1494	Mar. 24.	Chuching-fu (Yunnan). (Hoang, September 16.) III
1495	April 10.	Ninghsia-fu in Shanhan (Kansu). III
1497		Chenting-fu (Chi-li), Ninghsia-fu, Yulin-fu, Chenfan-hsien, Linchou in Shanhan (Kansu), Taiyuan-fu, *Tungmo* (Shansi). I
1501	Jan. 19 to Feb. 4.	Repeated shocks in various parts of Shanhan (Kansu and Shensi), (Honan) and (Shansi). *Chaoyi-hsien* (Shensi). II
1501	Mar. 5 to April 2.	Puchou-fu (Shansi). I
1502	Oct. 17.	Nanking, Hsuchou-fu in Chang-nan (Kiang-su), Taming-fu, Shunte-fu (Chi-li), Chinan-fu, Tunchang-fu, Yenchou-fu, *Puchou* (Shantung). III
1505	July 10.	Ninghsia-fu in Shanhan (Kansu). II
1505	Oct. 16.	Nanking, Puchou-fu, *Anyi and Wanchuan* (Shansi). II (O. October 9, 10 and 16.)
1506	April 26 and 27.	Yunnan-fu and *Mumihuan* (Yunnan). II
1506	Aug. 28.	Fortress Aoshanwei, Laichou-fu (Shantung). II
1507	Nov. 4 to 6.	Yunnan-fu, Anchou, Hsinhsingchou (Yunnan). II
1511	Nov. 17.	Tali-fu (Yunnan), *Hoching and Chienchuan.* II
1512	Oct. 7 and 8.	Fortress Tengchungwei (Yunnan). II
1515	June 17 to July 17.	Fortress Yungningwei (Yunnan). III
1517	July 12.	Hsinhsing-chou, Tunghai, Hosi, Hsio (Yunnan). III

A.D.		
1520	Aug. 18.	Fortress Chingtuwei (Yunnan). II
1523	Jan.	Fenyang-fu in Changnan (Kiangsu), (Shantung), (Honan) and Shanhan (Kansu). I
1523	Aug. 14.	Fortress Tinghaiwei (Chekiang). II
1526	May 21.	Tengchung (Yunnan), Annanwei (Kweichou). I
1555	Jan. 23.	(Shansi), Shanhan (Kansu) and (Honan), *Huachou, Weinan-hsien, Chao-i-hsien, Sanyuan-hsien* and *Puchou-fu* (Shansi). (Hoang, 1556, January 23.) III
1556	April 1.	(Shansi). III
1558	Nov. 24.	Huachou (Shansi). II
1561	Feb. 21.	Fortress Shantanwei (Kansu). II
1561	June 5.	Taiyuan-fu, Tatung-fu (Shansi), Yulin-fu, *Ninghsia-fu, Kuyuan* in Shanhan (Shensi and Kansu). (Hoang. August 4.) III
1562		Ninghsia-fu in Shanhan (Kansu). II
1568	April 1.	Chingyang-fu, Huan-fu, Hangchung-fu, Ninghsia-fu in Shanhan (Kansu and Shensi), Anyi and Puchou-fu (Shansi), Yunyang in Huhuan (Hupeh) and (Honan). I
1568	May 2.	Fenghsiang-fu, Hsian-fu, Pingling-fu and Chingyang-fu in Shanhan (Shensi and Kansu). II
1574	Mar. 10.	Changting (Fou-kien). II
1577	Mar 12 and 17.	Tengyuehting (Yunnan). III
1580	Sept. 5.	Chingfing-lu (Chi-li). II
1584	June 17.	Erzingan. III
1590	June 27.	Lingtao (Kansu). (O. July 7.) II
1591	Nov. 11.	Shantanwei (Chi-li). II
1596		Nizhni-Novgorod. III
1598		Amasia and Chorum. III
1603	May 20.	Chunghsien-hsien in Chentiang-fu (present Anlu-fu in Hupeh). (O. and H. May 30.) II
1604	Oct. 15.	Kungchang-fu and Litsuan-hsien in Shanhan (Kansu). (O. and H. October 25.) II
1605	July 3.	Luchuan (Kwangsi). (O. July 14.) II
1609	July 2.	(Kansu), especially *Kunei and Tsingshui.* (O. July 13.) III
1612	May 24.	Tali-fu and Chuching-fu and Wuting (Yunnan). (O. July 2, H. June 3.) III
1615	Feb. 19.	Yanchou-fu in Changnan (Kiangsu). (O. March 1.) II
1620	Feb. 24.	In Yunnan, Chaoching-fu, Huichou-fu (Kwantung), Chingchou-fu, Chengtan-fu (Hupei). (O. March 5.) I
1622	Mar. 8.	Chinan-fu and Tungchang-fu (Shantung). (O. March 18.) III
1622	Oct. 15.	Pingliang-hsien and Lungte-hsien (Kansu). (O. October 25). III
1624	July 7.	Paoting-fu (Chi-li). (O. July 20.) II
1626	June 18.	Pekin, Chinan-fu, Tungchang-fu (Shantung), Honan-fu (Honan), Tiantsin-fu, Hsuanhua-fu (Chi-li), Tatung-fu (Shansi). (O. June 28.) III
1627	Jan. 6.	Ninghsia-fu in Shanhan (Kansu). II
1627	Feb. 6 to Mar. 8.	Ninghsia-fu. III
1631	July 11.	Lingtao-fu and Kungchang in Shanhan (Kansu). (O. July 22.) III
1641	Feb. 5.	Tabriz in Persia, and environs. III
1648	April 2.	Town of Van, Armenia. III
1667		Shemakha in Caucasus. III
1669	Jan.	Shemakha and Lacha, Caucasus. III (Perhaps the same as 1667.)
1670		Shemakha. II
1670	Dec. 22 and 23.	Shemakha. III
1670	Jan. 22.	Shemakha. II
1671	Aug. 8.	Shemåkha. II
1679	June 4 to 12.	Erivan and neighbourhood as far as Ararat. (v. Hoff, 1680.) III

A.D.		
1680		Various parts of Europe and Asia, especially Italy and Poland. I
1700	June or July	Nerchinsk in Siberia. I
1716		Dzungaria, Baikal and Zaisan, *Aksu* on southern flank of Tian-shan. III
1718	June 8.	Singansan or Sinsusu (cap. of Shansi?) and in Tongwei and Tin-miuchin (Si-ngan, cap. of Shensi?) (June 10, Chinan, in Chanchou, Tungwei, Kungchang-fu (Kansu) H.) II
1719	July.	Northern China. III
1720	June 11.	Pekin. (O. West of Pekin.) II
1724	May 31.	Pekin and many parts of (Shansi). III
1725	Jan. 21.	Chita in Transbaikalia and west to R. Selunga. I
1731	Nov. 19.	Pekin and neighbourhood. III
1737	Oct. 6.	Around Avacha in Kamchatka and Kuriles. III N.E. 4° × 1°.5.
1737	Sept. 23 and Oct. 23.	(Perhaps identical with preceding). Nizhne-Kamchatka fort. II
1737	Dec. 6.	Kamchatka and the Kuriles. II
1742	Feb. 7.	Bering Island. II
1742	June 16.	Irkutsk. I
1742	June 16.	Bering Island. III
1755	Nov. 1.	The Lisbon Earthquake. III
1756		Kamchatka. III
1758	Dec. 7.	Russian Lapland, Kola town. II
1761	Dec. 9.	Kolyvan factory and Ubinskaya fort and Chagirskaya fort, W. Siberia. I
1766		Province Pasin (Bassen) Armenia. II
1769	Oct. 24.	Irkutsk and Selenginsk. I
1772	Feb. 18.	Town of Kola, Russian Lapland. I
1772	Dec. 5.	Irkutsk, Selenginsk and Kiakhta. I
1776	Dec. 9.	Barguzin fort, Transbaikalia. I
1779	Aug. 1.	Irkutsk, Balagansk, Selenginsk. I
1783		The Calabrian Earthquake, shocks felt this year also in parts of Asia, especially the Altai.
1784	early in August	*Erivan*, Armenia extending to Erzerum, *Mush and Gyeghi.* III
1786	Feb. 27.	Upper Silesia, Bohemia, Hungary and Poland. I
1788	July 22.	Aleutian Islands in Unga. III
1788	in Spring.	Prov. of Balu (Palu?). III
1790	April 6.	S. Russia, Galicia, Transylvania, the Bannat and Rumania, and felt as far as Constantinople. III
1791	April 15.	Nizhne-Kamchatsk. II
1792	Aug. 23.	Petropavlovsk, Nizhne-Kamchatsk, Paratunka and all east coast of Kamchatka. II. N.N.E. 4° × 1°.
1798	May 23.	Perm, Kungur and villages of Perm, Kungur, Oca and Verkhoturye districts. I
1802	Oct. 26.	From Ithaca and Constantinople to St. Petersburg and Moscow, especially in *Wallachia*, *Moldavia* and the south of *Transylvania.* III
1802		Aleutian Islands. II
1803	Jan. 8.	Belostok, Grodno Government. I
1803	Oct. 29.	Tiflis. I
1804	Oct. 11.	Tiflis. I
1806	April 22.	Irkutsk. I
1806	Aug. 8.	Krasnoyarsk. III
1809	Mar. 10.	Viatka and district. I
1814	Sept. 3.	Irkutsk, *Tunkinsk* fort and surrounding villages. III
1814	Dec. 17.	Irkutsk and felt as far as Troitskosavsk, 345 miles distant. I
1817	April.	Chang-li (Sze-chuan). III
1819	Jan. 29.	Tiflis. I
1820	Mar. 7.	Irkutsk and around the *Turansk* frontier post. I
1821	Nov. 17.	Almost all the south of Russia, especially in *Jassy* in Rumania, Dubossari, Nikolaief, Olviopol, Ochakof. I

A.D.		
1827	May.	Kirensk in Irkutsk Government and in Petropavlovsk village, 53 miles from Kirensk. I
1827	Oct. 21 to 23.	Tiflis and Stavropol, Caucasus. I
1827	Nov. 16.	Santa Fé de Bogota followed by earthquake in Okhotsk on the 17th. I
1827	June.	Commander Islands. III
1828	Aug. 7 to 14.	*Old Shemakha*, Shusha and many villages in the Caucasus. III
1828	Mar. 7 to 19.	Irkutsk, Troitskosavsk, Kiakhta, Turansk frontier post. III
1829 •	Nov. 26.	Bukharest in Wallachia (Centre), *Wallachia, Moldavia and Bessarabia*, and felt over all S.W. Russia, Galizia, Bukovina and Transylvania. III
1829	Nov. 31.	Barnaul and Suzun smelting-works. I
1830	Mar. 9.	*Tiflis, Georgief* district, Kizlar, Mozduk, Ekaterinodar, *Andreiej village, Tarka.* III
1830	June 25.	Vnezapnaya, Caucasus. II
1830	June 26 and 27.	Huaiching-fu (Honan) and parts of (Chi-li), south of Pekin. (H. June 12–13.) III
1830	Dec. 4.	*Anapa* and Taman Peninsula. I
1830	Dec. 26.	230 miles from Pekin, perhaps identical with June 26. III
1831	May 19.	Turkinsk mineral springs, near Lake Baikal. I
1832	Jan. 22.	Bokhara, Kokand, Badakshan and Upper Oxus. III
1834	Feb.	Anapa, Bugaz and shore of Abkhasia. I
1834	July 10 to 22.	Changte-fu (Honan), especially in the district of Wungang, westwards to (Shansi), northwards to (Chi-li) and east to (Shantung). (O. June 28–July 19.) III
1835	April 21.	Bessarabia and Bukharest. I
1835	July 20.	Lemberg. I
1835	April 14.	Pribylof Islands. III
1838	Jan. 23.	S.W. Russia, Wallachia, Moldavia, Transylvania, Hungary and Balkan Peninsula. III
1839	June 28 and 29.	Village Fedorovka, Saratof Government. II
1839	Aug. 18.	Irkutsk and along the Selenga R. III
1840	July 2.	In the departments of Surmala, *Sharur* and *Nakhichevan* in the Talyshef Khanate and the Ordubat district. III
1840	July 6–8.	Ararat, Sharur and Nakhichevan districts. III
1840	July 27.	Ararat and Sharur. III
1840	Dec. 7.	Sharur and Nakhichevan. II
1841	May 18.	Village Kevragh, also in Nakhichevan. II
1841	May 18.	Petropavlovsk and Ostrovnoe. II
1841	Sept. 22.	Nakhichevan and neighbourhood. I
1841	Dec. 25.	Anapa, Nikolaievak and Vitaz. I
1842	Jan. 2.	Baku and neighbouring villages. III
1843	Oct. 2.	Bessarabia, Baltain Podolia, Soroki in Bessarabia and Odessa. I
1845	May 24.	Akhaltsyk and district. II
1846	Jan. 11.	Nakhichevan. I
1846	April 23.	Javarisi, Kutais Government. II
1846	Aug. 18.	*Irkutsk* and Kirensk. I
1847	May 15 or 16.	Kushva, Verkhnaturye, Nizhneturye and Bisert mines and works in the Urals. I
1848	Sept. 22 to 25.	Shemakha. I
1849	Jan. 29.	Ishim in Tobolsk Government. I
1851	April 13.	Nakhichevan district in Erivan Government. I
1851	Nov. 28.	Okhotsk Dept. along coast of the sea of Okhotsk from the Taui to the Tuman post, 470 miles. II N.E. $3^{\circ} \times 1^{\circ}.5$.
1852	June.	(Kansu), China. III
1852	July 24.	Erzerum. III

A.D.		
1853	Jan. 18.	Demijan monastery and village of Chubukhly, Tiflis district and Sevanga Island. II
1853	April 14.	Shanghai; village 30 miles from Shanghai completely ruined. II
1856	July 11.	Shemakha. III
1856	Aug. 14 to 17.	Southern part of (Chi-li), China; *Yuching*, 20 miles from Pekin destroyed. III
1857	Dec. 24.	Semipalatinsk Province and Tomsk Government, especially Kok-pektinsk and Ust-Kamennogorsk. I
1859	June 2.	Erzerum and neighbourhood, especially in the mountains Palenjukan and Yarlydagh III
1859	June 12 and 13.	Shemakha. III
1859	June 26.	Shemakha and Erzerum. I
1859	July 13.	Tiflis and Erzerum. I
1860	Nov. 4.	Belii Kliuch, Caucasus. I
1861	Feb. 16.	Sunday Islands. II
1861	Feb. 22.	Copper Island, Bering Sea. I
1861	Mar. 5.	Shemakha. I
1861	Dec. 17.	Alkan-zhurt? and Samasha stations in the Caucasus. I
1862	Jan. 12 to 31.	Irkutsk, Selenginsk, Verkneudinsk, Chita, Petrovsk, Nikolaievsk, Upper and Lower Angora Districts. E.S.E. $9^{\circ}.5 \times 7^{\circ}$. II
1862	April 28.	Selenginsk. I
1862	Dec. 19.	Lenkoran, Shemakha and Shusha. I
1862	Nov. 29.	Shemakha. I
1864	Jan. 3.	Environs of Ardebela, Persia. Also felt at Lenkoran, Karabagh and Shirvan. III
1864	Jan.	Hankow, China. III
1865	Mar. 22.	Merke in Turkestan Province. I
1865	May 22.	Selenginsk, Irkutsk, Verkhneudinsk. I
1865	May 27.	Poretskoe, Simbir Government. II
1865	Sept.	Around the Taishan Mountain (in Shan-Tung), China. III
1866	Mar. 8.	Verkneudinsk and Irkutsk. I
1866	Aug. 25 or Sept. 6.	Petropavlovsk and Lyersny. I. II
1866	Nov. 4.	Soroki, Bessarabia. I
1867	May 5.	Pekin. I
1867	May 7 and 8.	Selenginsk. I
1867	July 23.	Telaf, Shemakha, Mukhravan, Zurnabad and Elizavetpol. I
1868	Feb. 4.	Tashkent. II
1868	Feb. 18.	Akhalkalaki, Kvirila, Toporovan, L., and Ardahan in Kars Province. I
1868	Feb. 25.	Erzerum, Alexandropol, Akhalkalaki. II
1868	Mar. 18.	Telaf, Delizhan, Shusha, Jebrail, Zakatali, Shemakha, Belasuvar, Chatakh. I
1868	Mar. 21.	Grozny and *Gorachevodsk* station. I
1868	April 4.	Tashkent. II
1868	April 11.	Kars and Nizhni-Pasin, Erzerum, Tiflis. II
1868	June 30.	Tsogonoi village, Tersk Province. II
1869	Dec. 10.	Khojent. I
1869	Sept. 2.	Shemakha and the Kuban district over 2,200 square miles. Most violent in Sundi, 12 miles from Shemakha. III
1869	Nov. 1.	Valley of the Barguzin river, Lake Baikal. I
1869	Dec. 26.	Tiflis, Alexandropol, especially villages Malye, Jamzhili and Jan-shtan. III
1870	April 11 to 21.	Batang (Sze-chuan), China. III
1870	July 7 and 8.	Eastern shore of Black Sea. I
1871	Mar. 4.	Irkutsk Government and Transbaikal Province and North Mongolia. I

A.D.		
1871	Dec. 11.	Gulija, 56 miles west of Erivan, and in the Echmiadzin district. II
1872	Jan. 28 to Feb. 19.	Shemakha and neighbourhood. III
1873	Oct. 15.	Monastery Kopenkovat, Uman District, Kief Government. II
1874	Aug. 24.	Nazran fortress, 16 miles from Vladikavkaz. I
1875	July 25.	Sebastopol and neighbourhood. I
1875	Aug. 7.	Shemakha and its district. III
1875	Aug. 17.	Grubesheva, Lemberg Government. I
1877	Aug. 8.	Oni and Utseri on River Rion. I
1878	Mar. 28.	Bakhti fort in Sergiopol district. I
1878	Mar. 31.	Gorachevodsk convict settlement in the Caucasus. II
1878	May 4.	Village Ullu-gatam in S. Daghestan. II
1878	July 16	Fort Kishan-aukh, Tersk Province and neighbourhood. I
1879	Jan. 8	Alaghir, Tersk Province. I
1879	Mar. 22.	Ardebela, villages on S. and S.W. foot of Savalan mountain, Armudagh and other places on road from Teheran to Tabriz. III
1879	June 29.	Dep. (Kuangsu), China. III
1879	Oct. 9.	Varenska, Gostagaievska, Troitzkaya and *Kurgan* stations in Transkuban Province. I
1879	Oct. 28.	S. Hungary and felt in Transylvania, Servia, Rumania and Bessarabia. III
1880	Oct. 22.	Shemakha. I
1880	Dec. 2.	*Verny*, extending to Kurumdof and Karakul. I
1880	Dec. 25.	*Odessa* and felt in Bessarabia and Rumania. I
1881	Jan. 31.	Petrovsk, Transbaikalia. I
1881	May 30.	Van, village of *Tegut* and environs. III
1882	July 19.	Temir-khan-Shura, Caucasus. I
1883	May 3.	Tabriz and most of Azerbaijan. I
1883	Nov. 3.	Karakoyunli, 30 miles from Erivan. II
1883	Nov. 14.	Tashkent and Osh in Fergana. I
1883	Nov. 18 to 24.	Sultanabad, 20 miles from Osh, and Osh. II
1884	Jan. 26.	Tali-fu (Yunnan). II
1884	Dec. 19.	Shusha. I
1885	Jan. 12.	Villages Kabansk and Barguzinsk, east of Lake Baikal. I
1885	Middle of May.	Village of Sikukh, N.W. of Derbent. II
1885	Middle of June.	Village Shishkina, 33 miles from Orenburg. II
1885	Aug. 3.	Sukuluk, Belovodsk and Karabalti and extending to Tashkent, to Verny and to Ili. III
1885	Oct. 9 to 25.	Tokmak district, Semreachie. I
1886	Jan. 4.	Chembar, Penza Government. I
1886	June 27.	Shemakha. I
1886	Nov. 8.	Tokmak and Verny. I
1886	Nov. 29.	Tashkent. II
1887	Jan. 14.	Semipalatinsk, Usk-Kamennogorsk, Altai district and Biisk district. I
1887	June 9 to 28.	Verny, Sophiisk, Kopal, Gabrilovka, Aksu, Karakul (Przhevalski), valley of the Ili. III
1887	July 16.	Batum, Ozurgeti and *Kutai.* I
1887	Sept. 9.	Russian Turkistan, Verny. II
1888	April.	In (Yunnan), especially the towns *Shipin, Chenshui* and *Peiyuangting.* III
1888	May 15.	Russia, Erivan. I
1888	Sept. 16.	Russian Turkistan, Verny and Pishek. I
1888	Sept. 22.	Ardahan, Okan, &c. II
1888	Sept. 23.	Transcaucasia, Batum. I
1888	Sept. 23 to 26.	Kars and other places in the Kars Province. II

A.D.		
1888	Nov. 28.	Tashkent, Khojent and places east of Tashkent.
1888	Nov. 29.	Verny and Kopal. I
1888	Dec. 3.	Verny. I

A List of Destructive Earthquakes in Iceland.[1]

Abstracted by C. A. GOSCH, Esq., from 'Landskjálftar á Islandi,' by Thorvald Thoroddsen, Copenhagen, 1899-1905.

The work from which the following abstract has been made was issued by the Icelandic Literary Society in two parts, of which the first, pp. 1-200, was published in 1899; the second, pp. 201-266, in 1905.

The relative 'destructivity' is indicated by the numerals I, II, and III, see p. 57.

Earthquakes in Iceland appear to be closely connected with local volcanic activity, and it is therefore convenient to group them according to the volcanic areas in which they originate, as Mr. Thoroddsen has done. Occasionally, however, an earthquake extends from one area to another, so that by this arrangement the same seismic disturbance may have to be mentioned in more than one list. The principal earthquake area in Iceland is that of the Sudurland, the southern part of the island, and particularly the Sudurland underland,[2] which means the lowlands in that part of Iceland. This district lies between the central plateau and the south coast, and is bounded to the east by the mountains about the Myrdals jökull, near the southernmost point of the island; and to the west by a ridge, which on the western side slopes down to the Faxa Bay (Faxa flói or Faxa fjördr). It is an alluvial plain, which fills up a prehistoric bay of the sea, in which isolated rocks and mountains represent ancient islands. The extent is given by Mr. Thoroddsen as '70 sq. milur,' or about 1,300 English square miles. The principal seat of volcanic activity here is Hekla, at the north-east corner of the district. The localities mentioned in Mr. Thoroddsen's list of earthquakes in the Sudurland are situated partly in Arnessysla, partly in Rangarsysla; 'sysla' being the appellation for certain administrative divisions. Arnessysla is the westernmost, the furthest from Hekla, and comprises the following subdivisions frequently mentioned—viz., Ölfus, the westernmost, west of the river Ölfusá, next Flói between the sea and the lower courses of Ölfusá and Thjorsá; to the north of these, inland, are Grimsnes Thingvallasveit, Bishopstungur, Skeid, and, finally, reaching up to the edge of the highland ice, the so-called Hreppar—viz., Eystrihreppur or Gnupverjahreppur and Hrunamannahreppur or Ytrihreppur. The river Thjorsá divides

[1] A second abstract of this work has been received from the Hon. S Allan Johnstone, British Minister in Denmark. Although in both cases these registers represent the selection by independent workers of earthquakes which were destructive, the one confirms the other.

[2] In Mr. Thoroddsen's paper the names are mostly given in the Dative case, governed by á; but in this abstract they are treated as would be English names and not declined.

Arnessysla from Rangarsysla, which comprises the districts of Holt, Land or Landsveit, Rangarvellir—the northern extremities of the two latter embracing the foot of Hekla—further to the east Hvolhreppur and Fliótshlid; finally, on the sea coast, Landeyjar and Eyafjallasveit.

The earthquake area of the Faxaflói lies on the west coast of Iceland, and comprises the districts bordering on that bay with the peninsula which forms the south-west corner of the island, terminating in Reykjanes, near which, in the sea, is the principal seat of volcanic action here. In this area are Bórgarfjördr, Reykjavik and Krisuvik in Guldbringasysla, which borders on Ölfus in Arnessysla.

The earthquake area of the Nordurland or North Country, comprises the whole northern coast of Iceland from Hunaflói eastwards, and the centre of volcanic action here is the Myvatnsveit, the district round the lake of Myvatn, where a number of craters exist.

The north-west part of Iceland, which forms a peninsula connected with the main island by a narrow neck, is rarely visited by earthquakes, at least noteworthy ones, and the same is the case with the east coast. Nor are many earthquakes recorded from the central part of the island or from the vast icebound, volcanic complex of mountains called the Vatna Jökull, which fills up the south-east corner of Iceland. The absence of more numerous records may, however, be due to the desolate almost inaccessible character of the region.

A List of Destructive Earthquakes in the Sudurland.

A.D.

1013 'Great earthquakes.' No date or particular locality is indicated. II

1151 No direct mention of an earthquake, but only that houses were destroyed and people killed in connection with an eruption of a volcano in the interior, the Trölladyngjur, literally the habitations of the gnomes, a name applied to several mountains in Iceland. No particular locality or date is given. II

1157 Earthquake in connection with eruption of Hekla, January 19. II

1164 Earthquake in Grimsnes; no date given. II

1182 Earthquake; no date or locality indicated. II

1211 Great earthquake, July 7; the locality is not particularly indicated, but it is stated that on the day before there had been an eruption in the sea south of Reykjanes, resulting in the formation of some new 'Eldeyjar' or Fire Islands. A group of islands of that name is still in existence. II

1240 Great earthquake throughout the south country; eruption off Reykjanes. No date. I

1294 Great and widespread earthquake in Fliótshlid and Rangarvellir; connected with an eruption of Hekla. No date is given. III

1300 Several earthquakes about Christmas time through the south country, contemporaneously with an eruption of Hekla, which commenced July 10 and lasted nearly 12 months. II

1308 Great earthquake throughout the South Country. No date. II

1311 Earthquake in the night between January 10 and 11. No particular locality indicated, but it is stated that on January 25 there was an eruption in the Austurjökulls. I

1339 Severe earthquake throughout the South Country, May 22. It was felt mostly in Skeid, Flói and Holt. III

1370 Earthquake in the South Country about Ölfus. No date. II

1389–90 Earthquake in the South Country; no particular place or date mentioned. There were eruptions from Hekla, Trölladyugjar and Sidu Jökull. II

1391 A great earthquake throughout the South Country, particularly in Grimsnes, Ölfus, and Flói. III

1510 Earthquake at Skalholt, about 20 miles west of Hekla, in connection with an eruption of the volcano on July 26. I

A.D.
1546 Earthquake at the end of May, mostly in Ölfus. II
1552 Earthquake shocks at Candlemas eve (March 2); no locality mentioned. I
1554 Severe earthquakes which lasted through half a month, so that people had to live in tents. No particular locality mentioned, but it is stated that at the same time an eruption of Hekla was going on, which lasted six weeks. The date is given as between Crossmass (the Festival of the Invention of the Cross, May 3) and 'fardag,' which means the last four days of May. I
1578 Earthquake in Ölfus in the evening of All Saints' Day (November 1), supposed to be caused by an eruption of Hekla, which was going on during that autumn. II
1581 Great earthquake in the month of May (between Crossmass and fardag), particularly in Rangarvellir and Hvolhreppr. III
1584 'Great earthquake in Iceland, but it is not known in what part it happened; most probably, however, in the South Country.' II
1597 Several severe shocks of earthquake at Skalholt on January 3, in connection with an eruption of Hekla. In the same spring, after the eruption of Hekla, there was a destructive earthquake in Ölfus. II
1613 An earthquake in the South Country, particularly severe in Skeid. II
1619 Earthquakes after midsummer, also eruption of Hekla; no particular date or locality mentioned. I
1624 Continual earthquakes all through November, particularly in Flói. II
1630 Three earthquakes during the winter, one on February 21, throughout the South Country. Damage done at Skalholt, &c. II
1638 An earthquake in the South, did damage at Ölfus; no date given. II
1657 Great earthquakes in the South and in the West, mostly in Floi and in Fliótshlid, where damage was done, March 16. III
1671 Great earthquake in the summer in Grimsnes and Ölfus. III
1693 Strong earthquakes all over the Sudurlandunderland, which were also felt at sea, connected with an eruption of Hekla which commenced February 13. I
1706 In the course of the winter there were several earthquakes—viz., two in the evening of January 28, one in March, one on April 1, and the most severe on April 20 in the morning which wrought great destruction in Ölfus. It was also felt in Flói and even, though weaker, in the Faxaflói area. III
1724 Earthquakes in the month of August, mostly in Arnessysla. This disturbance reached Krïsuvik in the Faxaflói area and was felt strongly at Reykjanes Skaga. II
1725 Between April 1 and 2 there were terrible earthquakes in Arnes- and Rangarsysla. In the same morning fire burst out of the ground round Hekla. III
1726 Earthquakes late in the summer in Rangarvellir. In the winter there had been an eruption in the Eastern Jökulls. II
1732 Severe earthquake on Sept. 7 in Rangarvellir and Eystrihreppr; the people took to living in tents, as the shocks continued for nearly half a month. II
1734 On March 21 a severe earthquake occurred in Arnessysla, particularly in Flói.
1749 A severe earthquake in the Sudurland, particularly in Ölfus; it was felt also in Borgarjördr and elsewhere in the Faxaflói area. II
1752 Earthquakes occurred during the winter in Ölfus. II
1766 Many earthquakes in the country round Hekla during an eruption which commenced April 5. The shocks were felt particularly to the south-west of the volcano and were destructive in Arnessysla, particularly in Ölfus, on September 9 and 10. They spread west to the Faxaflói area (Reykjanes) and south to the Vestmanna Islands off the coast. Two to four shocks were generally experienced every twenty-four hours. III
1784 On August 14 and 16 there were severe earthquakes all over the Sudurland, 'the worst that had happened in Iceland since the land became inhabited.' They were strongest in Arnessysla and Rangarsysla, particularly the former, but were felt all over the south, and spread not only to the Faxaflói area (Snæfell), but even to Isafjördr in the extreme north-west of Iceland.

The Vestmanna islands also were severely shaken, and shocks were felt even in Skaptafellsysla, east of Rangarsysla towards the Vatna Jokvill. The seismic disturbance lasted till Christmas. III

A.D.

1789 Severe earthquakes all over the south-west country, principally in Arnessysla. They commenced on June 10, and for a week after there was hardly any quiet time night or day; there were scarcely ten minutes between the shocks, and some were felt afterwards during the summer. III

1797 Earthquake shocks occurred on September 19 in Hvolhreppr. I

1799 Earthquake shocks were noticed in the morning of March 31 and the following day in Fliótshlid and Landeyjar. I

1808 An earthquake worth mentioning occurred. No date or locality given. I

1810 A strong earthquake was noticed east of Hekla, and also southwards, October 21. I

1828 Severe earthquake in Fliótshlid and Landeyjar. No date given. II

1829 On February 21 and in the night following there were earthquakes all over Sudurland. I

1838 June 12 in the morning early a notable earthquake occurred at Eyrirbakki, in Flói, which was also felt in the Nordurland between Hunaflói and Skjalfandi; at least there was an earthquake there on the same day. II

In the south the shocks continued to June 17. II

1845–7 Weak earthquake shocks occurred in the country round Hekla during an eruption which lasted from September 2, 1845, to April 6, 1846. They reached almost 28 English miles south-west of the volcano, but only 9–14 miles north-east of the mountain. Shocks were noticed in various places in the district, especially from October 4 to 13, 1845, January 11 to 18, March 5 and April 4, 1846, After the eruption had ceased, shocks were observed in this district on April 18, May 3 and 8, June 5, November 26, 1846, and January 7, March 2 and 3, 1847. The shocks on May 3, 1845, were felt also in the Faxaflói area, at Krisuvik and Reykjavik, where shocks were felt also on May 4, August 31, 1846, and February 15, 1847. During the eruption some shocks were felt in the Nordurlandar, and sharp shocks were felt during April and May 1847 at Grimsey, an island north of Iceland, just under the Arctic circle. I

1868 Earthquakes in the Sudurland, November 1 and during the week following. This disturbance originated in the Faxaflói and is mentioned on the list for that area.

1878 Earthquakes, February 27, in the whole of the south-west of Iceland, particularly in Land, Rangarvellir, the Hreppar, Fliótshlid, and the Vestmanna islands, but were not felt in all places at the same hour. At the same time there was an eruption of flames, in the lava fields north of the Krakutind, to the north of Hekla. I

1887 October 28. Earthquake at Eyrarbakki in Flói, where the disturbance lasted 10 seconds, and the direction was from north-north-west to south-south-east; at Kirkjubæ in Rangarvellir, where the direction was from north-west to south-east; also in Fliótshlid, Landeyjar, and Holt. This earthquake extended to the Faxaflói area. II

1889 Earthquake shocks at Rangarvellir on April 19, the direction being from east-south-east, and at Eyrarbakki in Flói, April 30, where the first shock lasted three seconds, but the principal one, a full second, the direction being from east-south-east to west-north-west. I

1896 August 26 and 27, and again September 5 and 6, more or less severe earthquakes occurred in all parts of the Sudurland and on the Vestmanna islands. Several districts were shaken again on September 10. III

These earthquakes were felt at several distant localities such as Hornafjörd on the south-east coast, though not, as it appears, in the Skaptafellsysla, between the Sudurland underland and Hornafjörd. They were felt at Reykjavik (August 26 and 27 and September 5), Börgarfjördr and elsewhere in the Faxaflói area, and on the north-west coast of Iceland even at Isafjördr in the extreme north-west. III

1899 The extensive earthquake in the Nordurland after New Year was felt in the Sudurland, particularly at Eyrarbakki (Flói) on February 27. I

The disturbances on the Sudurland in 1887, 1889, and 1899 are not mentioned by Mr. Thoroddsen on his list of earthquakes there; but in the list of earthquakes in the Faxaflói,

A List of destructive earthquakes about the Faxaflói.

There are no old records of earthquakes in this area available.

A.D.

1663 Earthquake at Reykjanes Skaga. No date. I

1706 The great earthquake which devastated Arnessysla in the month of April would seem to have been felt, though faintly, near the Faxaflói, as it is mentioned in Mr. Thoroddsen's list of earthquakes in that district, but all the details mentioned by him there refer to localities in Arnessysla. I

1724 The earthquake in Arnessysla in August was felt at Reykjavik.

1754 Earthquake at Krisuvik. No date indicated. I

1825 January 18 and 21, shocks at Reykjavik. II

1860 September 20, earthquake shocks occurred at Reykjavik; the direction was south-west to north-east.

In the middle of June and between December 30 and 31 weaker shocks were noticed, having the same direction. I

1864 Earthquake in Reykjavik on February 16. I

1868 Frequent and strong shocks occurred in the beginning of November at Reykjavik and Börgarfjördr. They were also noticed in the Sudurland, November 1 to 7. II

1878 The earthquake in the Sudurland, February 27, was felt at Reykjavik; there were three shocks.

1879 Strong earthquakes at the end of May at Reykjanes Skaga and Krisuvik. At the same time there was an eruption in the sea off Reykjanes, near the Geirfuglaskeri, the last breeding-place of the Great Auk.

1887 The earthquake in the Sudurland, October 28, was felt at Reykjavik; there were two not very strong shocks. I

1889 October 13, strong shocks were felt at Reykjavik and other places round the Faxaflói. These were scarcely felt in the Sudurland, which had suffered from an earthquake earlier in the spring.

1896 The great earthquakes in the Sudurland in August and September were felt at Reykjavik, Börgarjördr and elsewhere round the Faxaflói. I

1899 The extensive seismic disturbance in the Nordurland after New Year was also felt round the Faxaflói, particularly at Reykjavik, February 27. I

Several earthquakes in the Sudurland at various times were felt about the Faxaflói, but were not destructive.

A List of destructive earthquakes in the Nordurland.

As regards this area, too, early records of earthquakes are almost absent.

1260 A great earthquake in the North, at Flatey, an island in the bay called Skjalfandi. No date. II

1618 Constant earthquakes continued night and day from harvest time to Christmas. Damage was done at Thingeyjarthing.

1724 Earthquake, May 17, in Myvatnsveit in connection with a series of volcanic eruptions in that district which lasted to 1730, during which time earthquakes were frequent.

1725 Earthquake in Myvatnsveit in connection with the first eruption of the volcano Leirhnukur, on January 11, and again April 19, in connection with the eruption of Bjarnaflaga.

1728 Several earthquakes occurred in the Myvatnsveit in connection with eruptions from four different craters in the district. The strongest was on April 18, but many minor shocks were noticed all through that year. I

1755 September 11 to 24, a series of earthquakes affected the north coast of Iceland along the shores of Skagafjördr, Eyjafjördr and Skjalfandi. Damage was done at Husavik and several minor places. The disturbance reached Grimsey Island to the north of Iceland, but there was no earthquake in Myoatvisveit nor in other parts of Iceland. Mr. Thoroddsen mentions that on October 17 commenced a violent eruption of the Katla in the Myrdals Jökull, south of Hekla, near the coast, and he reminds his readers that the famous earthquake at Lisbon occurred a fortnight later. III

A.D.

1838 In the night between June 11 and 12 an earthquake shook the north coast of Iceland, between Hunaflói and Skjalfandi, which was not felt strongly inland, but, like that of 1755, was very strong in the islands off the coast, Grimsey and Drangey. The movement came from the sea and travelled from the north-east to the west to the interior. This earthquake was felt in the Sudurland at Eyrarbakki, June 12. III

1867 December 31, in the early morning there was an earthquake along the north coast, particularly at Akureyri and Husavik, it reached to Vöpnafjördr, on the east coast; minor shocks followed in places to January 15, 1868. There was not at that time any eruption in the north country, but from August 27 to September 5 there had been an eruption in the Vatna Jökull in the south-east of the island. II

1872 A great earthquake was felt at Husavik and Akureyri in the night of April 18; it was felt also at several other places along the north coast. II

1874–5 From the week before Christmas to January 3, 1875, frequent but moderate shocks occurred in Myvatnsveit and throughout the Nordurland, mostly inland. Shocks continued near Myvatn to the spring, while eruptions took place in Dyngjufjöll, January 3, and again March 29, and also in the Myvatnsöræfa on February 18, but they were not of importance. I

1882 October 29, there was an earthquake in several places on the north coast, principally round Thistillfjördr, a bay near the north-east corner of the island.

December 21. The same district was affected, particularly Akureyri. I

1884 November 2. Sharp earthquakes occurred at Husavik, Kelduhverf, and Thistillfjödr. I

1885 January 25, a severe earthquake at Kelduhverf and elsewhere along the north coast. III

1897 May 3. Earthquakes occurred along the western part of the north coast. I

1899 In the early part of this year there were frequent but not severe earthquakes in Iceland generally. The strongest occurred on January 30 and 31, and February 26–28, along the north coast from Bordeyri on the Hunaflói to Akureyri. On the west coast it was felt at Holt, on the Onundarfjördr, February 26, and on the same day at Reykjavik. On the 27th shocks were felt at Eyrarbakki in the Sudurland. At Bordeyri the direction is stated to have been south-east to north-west, at Grimsey the shocks were thought to come from south and south-west. I

Besides the three lists above abstracted, Mr. Thoroddsen's book contains a general list of recorded volcanic eruptions and earthquakes in all parts of Iceland, among which the following may be noted, which are not included in the lists given above, as they occurred in Skaftafellsysla, which is not comprised in the Sudurland, but lies to the east of it.

1721 On May 14 strong earthquakes were connected with the eruption of the Katla in the Myrdals Jökull; they extended to Eyjafjöll and Fliótshlid in the Sudurland.

1727 August 2. There was a severe earthquake at Sandfell near the Oræfa Jökull in connection with an eruption of that volcano.

1783 June 1, a severe earthquake shook Skaftafellsysla; the disturbance lasted till June 8, when the great Skaftárgos, an enormous eruption from Skafta fell, commenced.

A Provisional List of Destructive Earthquakes of the Southern Andes, south of Lat. 16° (S. Peru, Chile, Bolivia, W. Argentina).

By Count MONTESSUS DE BALLORE.

The relative 'destructivity' of different shocks are indicated by the numerals I, II, and III, see p. 57.

A.D.	
1520 (?)	S. Provinces of Chile. (?)
1543	Tarapaca. (?)

A.D.		
1562	Oct. 28.	La Imperial, Coast of Arauco. Sea waves. III
1570	Feb. 9.	Concepcion. Sea waves. III
1575	Mar. 17.	Santiago. II (?)
1575	Dec. 16.	La Imperial as far as Castro. Sea waves. III
1582	Jan. 16.	Arequipa. III
1588		W. Coast of S. America. (?)
1604	Nov. 24.	Arica and Arequipa. Sea waves. III
1604	Dec.	La Serena. (?)
1615	Sept. 16.	Arica. III
1632		Esteco (province of Salta). (?)
1633	May 14.	Carelmapu. Earthquake (?). Hurricane
1643	Sept. 6.	Santiago. I
1647	May 13.	Santiago. III
1650	Nov. 10.	La Paz. II
1657	Mar. 15.	Concepcion. Sea waves. III
1681	Mar. 10.	Arica. (?)
1688	July 12.	Santiago. (?)
1690	July 9.	Santiago. (?)
1692	Sept. 13.	Esteco (Tucuman). (?)
1715	Aug. 22.	Moquegua. (?)
1724	May 24.	Santiago. (?)
1725	Jan. 8.	Lima and Arequipa. III
1730	July 8.	Concepcion. Sea waves. III
1734		Mision of Tarija in el Chaco. (?)
1737	Dec. 24.	Ruin of Valdivia. III (?)
1742	Mar. 23.	North of the peninsula of Patagonia, south of the Archipelago of Chonos (Territory de Magellan). I (?)
1751	Mar. 25.	Concepcion. Sea waves. III
1773	July 29.	Copiapo. III (?)
1775	Mar. 17.	Valparaiso. I (?)
1782	May 22.	Mendoza. (?)
1784	May 13.	Arequipa, Arica. (?)
1784	Good Friday.	Arica and Valley of Tambo. II
1787	Feb. 1.	Castro. I (?)
1787	Mar. 23.	Arequipa. I
1792	Nov. 30.	La Serena. (?)
1793	Aug. 7.	Arica. (?)
1796	Mar. 30.	Copiapó and Vallenar. III
1801	Jan. 1.	La Serena. III
1813	May 30.	Yca and Arequipa. (?)
1819	April 4, 3, 11.	Copiapó. III
1821	July 10.	S. Peru, Camana and Arequipa. III
1822	Nov. 5.	Copiapó and Coquimbo. II
1822	Nov. 19.	Valparaiso. Sea waves. III
1829	Sept. 26.	Valparaiso and Santiago. I
1829	Oct. 1.	Santiago. I
1831	Oct. 8.	Arica. I
1833	April 25.	Huasco. I
1833	Oct. 18.	Arequipa, Arica and Tacna. II
1834	July.	Yca. (?)
1835	Feb. 20.	La Concepcion and Talcahuano. Sea waves. III
1836	July 3.	Cobija. Sea waves.
1837	Nov. 7.	Valdivia. III
1843	Dec. 17.	La Serena. I
1844	Oct. 18.	Salto, Tucuman, Santiago del Estero. III
1845	June 3.	Arica. I
1847	Jan. 19.	Copiapó. I
1848–50	(?)	Santa Cruz de la Sierra (Bolivia). II
1849	April 9.	Destruction of San Luis (Argentina). III

A.D.		
1849	Dec. 17.	Coquimbo. With sea waves. I
1850	Dec. 6.	Santiago. II
1851	April 2.	Santiago. II
1851	May 26.	Province of Atacama. II
1854	Jan. 14.	Minas de Cruz de Cañas (Coquimbo). I
1859	Oct. 5.	Copiapó. I
1861	Mar. 20.	Mendoza. III
1861	Aug. 29.	San Carlos (Argentina). I
1862	Feb. 5.	Mendoza. I
1863	June 29.	Arequipa. I
1864	Jan. 12.	Copiapó. I
1866	July 23.	Copiapó. I
1868	Aug. 13.	S. Peru, Bolivia and North of Chile. Sea waves. III
1868	Oct. 12.	Copiapó. I
1869	Aug. 19.	Arica to Yca. Sea waves. I
1869	Aug. 24.	N. Chile and South of Peru. I
1870	Mar. 23.	Calama. (?)
1870	Mar. 25.	Mendoza. I
1871	Feb. 23.	Province of Cochabamba (Bolivia). II
1871	Mar. 24.	Santiago, Valparaiso. I
1871	Oct. 5.	Tarapacá. I
1871	Oct. 22.	Jujuy and Oran. III
1873	July 7.	Central Chile. III
1874	Oct. 26.	Santiago. I
1876	Feb. 11.	Illapel, Salamanca and Chalinga. II
1877	May 9.	N. of Chile, Iquique. Sea waves. III
1877	May 17.	La Paz. I
1878	Jan. 23.	Iquique, Arica, Province of Tarapacá. I
1879	Feb. 2.	Magellan Territory and Tierra de Fuego. I (?)
1880	Aug. 15.	Valparaiso, Illapel and Quillota. I
1882	Mar. 6.	Department of Paclin (Catamarca Argentina). II
1883	Oct. 1.	Arequipa. I
1884	Nov. 26.	Bolivia. I
1887	Sept. 23.	Yacuiba (Bolivia). I
1890	April 24.	San Felipe. I
1891	Aug. 15.	Central Bolivia. I
1894	Oct. 27.	La Rioja and San Juan. II
1898	July 23.	Concepcion. I
1899	April 12.	La Rioja, Catamarca, Tucuman, Rio Cuarto, Santiago del Estero. I
1900	Oct. 23.	San Luis. I
1903	Aug. 12.	Mendoza. I
1903	Dec. 7.	Vallenar. II
1904	Mar. 19.	Vallenar. II
1906	June 18.	Valparaiso and Valley of Aconcagua. II
1906	Aug. 16.	Valparaiso and Central Chile. III
1907	June 13.	Valdivia. II
1907	Aug. 14.	Mendoza. I
1908	Feb. 23.	Sierra Gorda (Antofagasta). I
1908	July 16.	N. Chile, S. Peru, W. Bolivia. I
1909	Feb. 11.	Candarave (S. Peru). I
1909	May 17.	Tupiza (Bolivia). II
1909	June 8.	Chañaral and Copiapó. II
1909	July 22.	Sipesipe (Cochabamba, Bolivia). III
1909	Sept. 20.	Tinogasta, W. Argentina. I

Investigation of the Upper Atmosphere in co-operation with a Committee of the Royal Meteorological Society.—Ninth Report of the Committee, consisting of Dr. W. N. SHAW (*Chairman*), Mr. E. GOLD (*Secretary*), Messrs. D. ARCHIBALD, C. VERNON BOYS, C. J. P. CAVE, *and* W. H. DINES, Dr. R. T. GLAZEBROOK, Sir J. LARMOR, Professor J. E. PETAVEL, Dr. A. SCHUSTER, *and* Dr. W. WATSON.

MEETINGS of the Joint Committee were held in the rooms of the Royal Meteorological Society on October 20, November 2, 1909, March 8, 1910. The Committee arranged to take part in the wide scheme of international ascent for the week December 6 to 11, 1909. During that period registering balloons were sent up at twelve or more stations distributed over the continent of Europe besides those in this country, where arrangements were made for ascents at Crinan, N.B., and Pyrton Hill by Mr. Dines for the Meteorological Office, at Manchester by the University, and at Ditcham Park, Petersfield, by Mr. C. J. P. Cave.

In addition to observations at land stations, registering balloons were to be sent up from the German cruiser 'Victoria Louise' near the West Indies, and Professor Palazzo arranged to make observations off the coast of Somaliland in an Italian vessel at the same time as a German boat, the 'Planet,' was co-operating in the Indian Ocean. Observations of pilot-balloons were to be made from three vessels of the German Lloyd line, crossing the regions of the trade winds, and special observations were to be made simultaneously on the Peak of Teneriffe. Registering balloons were to be sent up in the United States and India also, and cloud observations were made at observatories all over the world. It will be seen, therefore, how extensive a field of operations was included in the scheme.

The plan of the Joint Committee was to fill up a gap in the observations in the British Isles by sending up registering balloons from a place in the West of Ireland and to secure pilot-balloon observations from Barbados, which had already been the scene of very successful kite ascents by Mr. Cave. The British Association grant was specially allocated for the former purpose.

The Committee secured the services of Captain C. H. Ley, who had in 1908 been successful both with pilot and registering balloons in Ireland, and he decided, with the approval of the Committee, to make Dhulough, a place in the extreme west of Galway, his base.

Special arrangements were made in this country on account of the risk of losing the balloons in the sea if they were sent up in decidedly unfavourable conditions. The Meteorological Office sent telegraphic forecasts to the observers from Tuesday to Friday of the week of the ascents in order that they might send up two balloons on a single day near the middle of the week if favourable conditions prevailed rather than risk losing the balloons owing to unfavourable conditions later on by rigid adherence to the general plan of one ascent at 7 A.M. each day.

Thus at Pyrton Hill and Manchester the second balloons sent up on December 7 on the strength of a favourable forecast were both recovered and furnished good records, and the second ascent from Manchester on the 8th was equally successful.

Altogether eighteen of the balloons sent up in this country were recovered, and fifteen of these gave records to heights exceeding 10 km. The results have not yet been discussed, but an inspection of them shows at once interesting features. On the earlier days of the week these islands were situated in a region of low atmospheric pressure in which the gradients were small. All the records for this period showed that the upper limit of the convective region of the atmosphere was reached at heights between 7·5 and 8·5 km., *i.e.*, very much below the average. The conditions changed as a well-marked cyclone developed over Iceland, and the greater part of the area of the ascents lay in the limiting region between this cyclone and an anticyclone whose centre was over the North of Spain. The height of the upper limit mentioned above rose simultaneously with this change to 12 km. or more at each station. It fell again as a fresh cyclone from the Atlantic advanced over these islands, and in the last ascent, made at Ditcham on the Saturday afternoon while the centre of the cyclone was still west of Ireland, the height had decreased to 10 km., which is about the average for that time of the year.

It had been hoped that the ascents would furnish sufficient results to admit of a similar representation of the temperature conditions in December to that for July shown a year ago by Dr. Shaw. The critical ascents were those from Ireland, and unfortunately these were not a success. Balloons which might have proved quite satisfactory in normal July conditions turned out to be too weak for the weather prevailing at Dhulough in the international week last December, and, instead of rising with approximately uniform vertical velocity until they burst, they developed leaks and on this account floated in the air probably long enough to get clear of the land. Only two of the six sent up were recovered, and these did not reach great heights. The results obtained were:—

Height		Surface	0·5	1·0	1·5	2·0	2·5	3·0 km.
Temperature Degrees A	Dec. 9 7.40 A.M.	—	276°	276°	275°	273°	271°·5	269°·5
	Second balloon reached 1·5 km. only.							

The observations made with pilot-balloons in Barbados have been received and are being dealt with by Mr. Cave. The heights to which the balloons were observed range up to 5 km.

The Committee find that a stronger balloon than that ordinarily used can now be obtained at a slight additional cost, and they believe that by using such balloons a successful series of ascents in Ireland may be obtained even in winter conditions. They therefore recommend re-appointment with a grant of 30*l.* to carry out further experiments in conjunction with the international ascents in 1910-11.

Magnetic Observations at Falmouth Observatory.—Report of the Committee, consisting of Sir W. H. PREECE (*Chairman*), Dr. R. T. GLAZEBROOK (*Secretary*), Professor W. G. ADAMS, Dr. CHREE, Captain CREAK, Mr. W. L. FOX, Sir ARTHUR RÜCKER, *and* Professor SCHUSTER.

THE results of the magnetic observations at Falmouth Observatory for 1909 have been published in the Annual Report of the National Physical Laboratory, as well as in that of the Royal Cornwall Polytechnic Society. The mean values of the magnetic elements for the year are:—

Declination	17° 48′·4 W.
Inclination	66° 30′·6 N.
Horizontal Force	0·18802 C.G.S.
Vertical Force	0·43266 C.G.S.

The instruments were inspected by Mr. Baker, of the Kew Observatory, in October 1909, who reports that they were then in good order, and that the results of the absolute measurements made on October 15 were in good agreement with Mr. Kitto's latest observations. The results of the tabulations for the year were also satisfactory.

During the year the Magnetic Survey ship 'Carnegie' visited Falmouth, and was furnished with data of great value. An account of some of the results is given in a paper by L. A. Bauer and W. J. Peters, 'On the Complete Magnetic Results of the First Cruise of the "Carnegie," 1909-10,' published in 'Terrestrial Magnetism' for June 1910, from which the following is an extract:—

'The desire therefore arose to make assurance doubly sure with regard to deviations of any kind (constant or harmonic), and to swing the "Carnegie" in a locality as free as possible from local disturbances. Captain Chetwynd, Superintendent of the Compass Department of the British Admiralty, being appealed to for advice with regard to a British port fulfilling the desired conditions, recommended Falmouth.'

The article also contains a comparison of the values of the magnetic elements at Falmouth with those already obtained by the American observers and the British Magnetic Survey values dependent upon Rücker and Thorpe's observations, referred to October 18, 1909, 'with the aid of the valuable series of annual values of the Falmouth Magnetic Observatory.'

The figures are as follows:—

	D.	I.	H.F.
'Carnegie' Ship Observations	17° 45′·0 W.	66° 30′·0	0·1873
,, Land ,,	17° 45′·1	66° 30′·4	0·1878
British Magnetic Survey	17° 44′·8	66° 29′·1	0·1876

from which it will be seen that the agreement is very close.

The magnetographs at Eskdalemuir are now working satisfactorily, and it is hoped it will be possible to commence this year the regular tabulation of results. In view of the importance of comparing the regular magnetic variations obtained there with those found in the South

of England, the Committee think it most important that the Falmouth observations should be maintained, and they ask therefore for reappointmen, with a grant of 50*l*.

By an arrangement recently made between the Royal Society, the Meteorological Office, and the Treasury, the responsibility for the magnetic and meteorological work at Kew and Eskdalemuir now rests with the Meteorological Office. The Committee therefore recommend that the name of Dr. Shaw be added to the Committee, and that he be the Secretary of the Committee.

Geodetic Arc in Africa.—Report of the Committee, consisting of Sir GEORGE DARWIN (*Chairman*), Sir DAVID GILL (*Secretary*), Colonel C. F. CLOSE, *and* Sir GEORGE GOLDIE, *appointed to carry out a further portion of the Geodetic Arc of Meridian North of Lake Tanganyika.*

THE grant (100*l*.) has been paid to H.M. Treasury. The field work for which the grant was made has been completed, and the computations are finished, excepting the final reduction of the observations of latitude.

Report by Captain E. M. JACK, *R.E.*

The measurement of a portion of the 30th meridian arc, to the cost of which the British Association made a contribution of 100*l*., was carried out in the Uganda Protectorate in 1908-09, the *personnel* employed being as follows:—

British Section.—Observers: Captain E. M. Jack, R.E., and Mr. G. T. McCaw, M.A. Assistants: Lance-Corporals Jones, R.E., and Page, R.E. Medical Officer: Mr. C. L. Chevallier.

Belgian Section.—Astronomer: Dr. Marcel Dehalu. Assistant: Captain G. Wangermée.

The instruments used were two 10-inch Repsold theodolites, lent by the Intercolonial Council of the Transvaal and Orange River Colony; and a 3-inch zenith telescope, lent by the War Office.

Observations of terrestrial angles were made to heliostats by day and to acetylene lamps by night. Angles were measured on eight settings of the circle, two measures C.R. and C.L. being taken on each setting. Vertical angles were measured in the afternoon.

Latitudes were observed at fourteen out of the sixteen main stations. The Talcott method was employed, and usually 15 to 20 pairs of stars observed at a station.

Azimuths were observed at three stations, at each end and in the middle of the chain.

A base 16½ kilometres (10¼ miles) long was measured. Six invar wires were used, three being kept for reference purposes only, and three for actual measurement. No standard bar was carried. The base was divided into sections of about one kilometre, and each section was measured twice, each measurement being made with two wires. A third measure of a section was made in the few cases when there appeared to be an abnormal discrepancy between the first and second.

In all, sixteen main stations were occupied. The chain of triangulation extended from 1° 10′ N. to 1° 10′ S., and consisted of five figures, namely: a northern complex figure, including the base net; three quadrilaterals; and a southern tetragon, or quadrilateral with an additional centre-point. The width of the chain is about 30 miles; the longest ray was 47 miles.

Every station was permanently marked with an iron or brass peg, surmounted by a large cairn of stones, in the centre of which was fixed an iron beacon. The Uganda Government was informed of the position of all stations.

The work in the field took eleven months, from March 1908 to February 1909, of which a month and a half was occupied in base measurement. The atmospheric conditions for observing were bad, and delayed the work considerably.

The actual cost of the British Section was 3,750*l*. A good deal of expense was saved by the fact that the majority of the officers and men had been on the Anglo-Congolese Boundary Commission, and the expense of their journeys, camp equipment, &c., were thus saved to the Arc Survey.

Preliminary computations were carried out in the field as much as possible, and found useful in the subsequent precise calculations. The latter were undertaken on the return to England, and are now practically completed.

The absolute probable error of the base, taking into account all possible sources of error, was found to be

$$\pm\ 14.92 \text{ mm., or 1 in 1,108,000,}$$

a result which is considered very satisfactory.

The average error of closure of the triangles was

$$\pm 0''.812,$$

and the probable error of an observed angle

$$\pm\ 0''.390.$$

The final report, which includes a full description of the work of the survey, the methods adopted, the determination of the errors of the instruments, the measurement of the base, the adjustment of the triangulation, a discussion of the height of the datum point on Lake Albert, and the adjustment of the vertical observations, &c., is almost complete. There remains to be done the section dealing with the geodetic positions of the points. The computation of these positions from the triangulation is necessarily bound up with the results of the latitude observations, as an adjustment has to be made between the two. Unfortunately the latitude results have not yet been received from M. Dehalu; but as soon as they are, the final computation of the geodetic positions will be made and the report published.

It may be mentioned that, in addition to the main work of the survey, observations were taken with a view to determining the height of Ruwenzori and of the Mufumbiro volcanoes; and a connection was made with the survey of Uganda.

M. Dehalu also carried out a large number of magnetic observations.

The Study of Astronomy, Meteorology, and Geophysics.—Report of the Committee, consisting of Sir ARTHUR RÜCKER (*Chairman*), Professor A. E. H. LOVE (*Secretary*), Sir OLIVER LODGE, Sir J. J. THOMSON, Professors C. G. KNOTT, E. RUTHERFORD, A. SCHUSTER, *and* E. T. WHITTAKER, Drs. W. G. DUFFIELD *and* G. T. WALKER, *and* Mr. R. T. A. INNES, *appointed to report upon the provision for the Study of Astronomy, Meteorology (including Atmospheric Electricity), and Geophysics in the Universities of the British Empire.*

IN reply to a letter of inquiry, information was furnished by the acting heads of most of the Universities. The information in regard to Australasia was collected by Dr. Duffield, and in regard to South Africa by Mr. Innes. Dr. G. T. Walker contributed a *résumé* of the information in regard to India. All the information was received in 1909, but some of it too late for incorporation in a report to be presented at Winnipeg. The report was therefore deferred to this year.

In asking for information the Committee suggested that provision, such as comes within its cognisance, might take the following, among other, forms:—

(1) There may be Professors, Readers, Lecturers, or Demonstrators appointed to teach or give instruction in one or more of the subjects.

(2) There may be occasional courses of lectures or practical instruction, such as would be a course in geodesy given by a professor of astronomy, or a course in terrestrial magnetism or atmospheric electricity given by a professor of physics.

(3) There may be facilities for the training of observers in meteorology, seismology, or other subjects of the group, in cases where the University, or the city in which it is situated, possesses observing and recording stations.

(4) It may be possible to secure such facilities as those referred to in (3) if they are sought by intending students.

(5) Degrees, or diplomas, may be given by the university for proficiency in the subjects or in some of them.

(6) There may be scholarships or studentships by which pecuniary assistance could be given to persons engaged upon research in these subjects.

(7) There may be prizes or medals for the encouragement of such research.

The information received is summarised in the following statement: The numbers in brackets indicate the forms of provision according to the circular issued by the Committee; the capital letters indicate the subjects, as follows: A., Astronomy; A.E., Atmospheric Electricity; G., Geodesy; G.P., Geophysics; M., Meteorology; T.M., Terrestrial Magnetism. For instance, the entry '(4) M.' means that facilities can be secured for training an observer in meteorology. When additional information not coming under any of these heads

has been furnished it is entered under the number (8). The number (1) is used when regular courses of instruction are given; the number (2) when occasional courses are given. The Universities which are omitted from the list either sent no information or make no special provision for the study of any subject of the group.

United Kingdom.

ABERDEEN.—(4) M. (6) Some scholarships available.

BIRMINGHAM.—(4) M. (8) A small astronomical observatory.

CAMBRIDGE.—(1) A. and M. (2) M. (3) A. and M. (4) A. (5) A. a subject for mathematical honours; degrees for research in any of the subjects. (6) Various endowments available. Some scholarships specifically assigned to A. (7) Medal for A.

DUBLIN (Trinity College).—(1) A. (3) M.

DURHAM.—(1) A. (3) M. (8) It is proposed to arrange for the study of M., with special reference to A.E., at Armstrong College, Newcastle-on-Tyne.

EDINBURGH.—(1) A. (3) M. and S. (6) Scholarship available. (8) A prize, open to the four Scottish Universities, is offered by the Scottish Meteorological Society for an essay on a meteorological subject.

GLASGOW.—(1) A. (2) G.P. (3) M. (5) A. a subject for Final B.Sc. (6) Two bursaries and a fellowship for A.

LEEDS.—(1) M. (3) M.

LIVERPOOL.—(1) A. (2) M. (3) A. (4) A., S., M. (6) Scholarship available.

LONDON.—(1) A. and M. (2) T.M.

MANCHESTER.—(1) M. (2) M. (3) M. (5) M., or any other subject of G.P., can be taken for an honours degree, also M. for diploma in public health. (6) Two scholarships and one fellowship available. (8) Meteorology is recognised as part of physics. A lectureship has been assigned to it, but is not now filled up. Students have taken part in investigations of upper atmosphere and atmospheric electricity.

OXFORD.—(1) A. (3) A. and M. (4) A. and M. (5) A. a subject for a final honours school; degrees for research in any of the subjects. (6) Various endowments available. (7) Medal and prize for an essay on a subject of A. or M.

WALES.—(1) A. (3) M. and S., at Cardiff. (8) A small astronomical observatory at Bangor.

Canada.

KINGSTON.—(1) A. (5) A. a subject for mathematical honours.

MONTREAL.—(1) A. (2) M. (3) A. and M.

TORONTO.—(1) A. (3) G. (4) A. at Ottawa. (8) Special courses are given to prepare students for posts on Geodetic Survey.

Australasia.

ADELAIDE.—(2) M. and T.M. (5) A. a subject for B.A. and B.Sc.

MELBOURNE.—(1) A. (2) G. (6) Research scholarships available.

NEW ZEALAND (CHRISTCHURCH).—(3) T.M. (5) A. a subject for mathematical honours. (7) Research medals available.

SYDNEY.—(2) A. and G. (3) and (4) A., G., and M. probably in future.

India.

Mathematical astronomy is generally a degree subject. At Calcutta there is a professor of A., and research scholarships are available for A.

General.

In several Universities atmospheric electricity, terrestrial magnetism, geodesy, meteorology, and seismology, or some of these subjects, are treated incidentally by professors of astronomy, physics, or geology; and it was intimated that additional provision could be made for the study of such subjects if there were any demand for it.

Electroanalysis.—Report of the Committee, consisting of Professor F. S. KIPPING (*Chairman*), Dr. F. M. PERKIN (*Secretary*), Dr. G. T. BEILBY, Dr. T. M. LOWRY, Professor W. J. POPE, *and* Dr. H. J. S. SAND.

THE work on electroanalysis has been further elaborated during the year by the publication of papers on the 'Electro-deposition of Metals,' by Dr. F. Mollwo Perkin and W. E. Hughes,[1] and by Dr. H. J. S. Sand on 'Apparatus for the Rapid Electro-analytical Separation of Metals,'[2] and 'The Electro-determination of Lead as Peroxide.'[3]

Perkin and Hughes have devised and experimented with new cathodes for the rapid deposition of metals. One simple, smooth cathode is in the form of an elongated thimble, and with this, when rapidly rotated, very smooth and even deposits can be obtained; the total active electrode surface is about 16·3 sq. cm. Extended work has shown, however, that a platinum gauze cathode surrounding a spiral anode, which is rapidly rotated, gives the most satisfactory results. For separation of metals by means of graded potentials a funnel-shaped vessel with a tap for running off the electrolyte is used. This vessel has a side tube fused into it at about the centre to take the capillary of the auxiliary electrode. This form of apparatus gave very good results, and is very simple in working.

The experiments referred to a year ago by Dr. Sand with an anode made partly of glass and a cathode of metals, other than platinum, have been completed by him, and will be published shortly. Satisfactory results for copper were obtained with a cathode of silver, and for zinc with a cathode of nickel. In the former case the electrolyte deposit may

[1] *Trans. Faraday Society*, 1910, vi. [2] *Ibid.*, 1909, v. 159. [3] *Ibid.*, 1910, v. 207.

be removed from the electrode by a solution of hydrogen peroxide in diluted sulphuric acid.

Experiments on the separation of the four metals—copper, antimony, tin, and lead—have been continued. In connection with this work it has been shown that chlorides exert a retarding influence on the deposition of copper. This is due to the formation of derivatives of cuprous chloride during electrolysis from which copper is only deposited at a high potential. The conditions for the separation of copper from antimony have been fully elaborated, and mixtures of the three metals—copper, antimony, and tin—corresponding to industrial alloys have been successfully analysed. When lead is present in small quantity this may be deposited with the tin; the greater part of the tin may afterwards be removed by making the electrode the anode in a solution containing sodium polysulphides. The lead may then be separated from the small quantity of remaining tin by means of nitric acid, and can afterwards be deposited electrolytically.[1]

Dynamic Isomerism.—Report of the Committee, consisting of Professor H. E. ARMSTRONG (*Chairman*), Dr. T. M. LOWRY (*Secretary*), Professor SYDNEY YOUNG, Dr. C. H. DESCH, Dr. J. J. DOBBIE, Dr. M. O. FORSTER, *and* Dr. A. LAPWORTH. (*Drawn up by the Secretary.*)

Absorption-Spectra of Camphor and its Derivatives.

THE study of a large number of derivatives of camphor[2] has shown that a band is normally present at a frequency 1/3500, but penetrating only to log. thickness 2·6 (about 400 mm. of N/1000 or 40 mm. of N/100 solution). This band appears even when the two hydrogen-atoms of the adjacent methylene group are displaced, provided that the new radicles do not possess any large residual affinity; but in compounds such as $\alpha\alpha'$-dibromocamphor, $C_8H_{14}\left<\begin{matrix}CBr_2\\ |\\ CO\end{matrix}\right.$, and $\alpha\alpha'$-chloronitrocamphor, $C_8H_{14}\left<\begin{matrix}CCl.NO_2\\ |\\ CO\end{matrix}\right.$, the general absorption is increased by the substituent groups, and the band disappears. The development of the band can only be attributed to the carbonyl-group, which is therefore capable of giving rise to a specific or local absorption: this is only of slight intensity, and of such a frequency as not to give rise to visible colour, but it may be compared not unreasonably with the blue or green colour produced by the analogous chromophore $-N=O$ in compounds such as *ter*-nitrosobutane.

[1] Preliminary note in *Proc. Chem. Soc.*, 1909, **25**, 228.

[2] *Trans. Chem. Soc.*, 1909, **95**, 807–823, 1340–1346; 1910, **97**, 899–905, 905–921.

The introduction of a second $\begin{array}{c}-C=O\\ |\end{array}$ group in compounds such as methyl methylcamphocarboxylate, $C_8H_{14}\left\langle\begin{array}{l}C(CH_3)CO.OCH_3\\ |\\ CO\end{array}\right.$, does not intensify the band, as the two carbonyls are not copulated owing to the fact that they are separated by two single linkages instead of one. In camphorquinone $C_8H_{14}\left\langle\begin{array}{l}C=O\\ |\\ C=O\end{array}\right.$, on the other hand, the band is brought right into the visible region at 1/2050 and its persistence is increased from log. thickness 0·3 to 1·6; the penetration of the band is, however, practically the same as in camphor, log. thickness 2·6, the decrease in the frequency of the maximum absorption being accompanied by no marked increase in its intensity. The decrease of frequency gives rise to what Schutze has called a 'deepening' of colour, an effect which he has conveniently described as 'bathochromic,' in contrast with the 'hypsochromic' action of compounds which cause an increase of frequency and a 'lightening' of the colour.

In methylene camphor, $C_8H_{14}\left\langle\begin{array}{l}C=CH_2\\ |\\ C=O\end{array}\right.$, the introduction of the second unsaturated group produces an entirely different effect, the frequency of the band being unaltered, but its penetration increased to log. thickness 1·7. The copulation of the two groups is thus accompanied by an actual increase of specific or local absorption, an effect which may be regarded as genuinely 'auxochromic.'

A further increase of penetration to log. thickness 0·3 is produced by the introduction of a third unsaturated centre as in benzylidene camphor, $C_8H_{14}\left\langle\begin{array}{l}C:CH.C_6H_5\\ |\\ CO\end{array}\right.$, and the derivatives of oxymethylene camphor, $C_8H_{14}\left\langle\begin{array}{l}C:CH.OR\\ |\\ CO\end{array}\right.$. The nature of the substituent radicle R in the enolic compounds,

$$(a)\ C_8H_{14}\left\langle\begin{array}{l}C:CX.OR\\ |\\ CO\end{array}\right. \quad \text{and } (b)\ C_8H_{14}\left\langle\begin{array}{l}C.CO\\ \|\\ C.OR\end{array}\right.,$$

has no marked influence on the penetration, but the frequency of the band decreases by about 200 units when sodium is substituted for hydrogen or methyl, whilst an increase of similar magnitude results from the displacement of hydrogen by acetyl; the bridging of the ethenoid linhage, which is the main difference between the enolic formulæ (*a*) and (*b*), is accompanied by a decrease of frequency.

The Study of Hydro-aromatic Substances.—Report of the Committee, consisting of Dr. E. DIVERS (*Chairman*), Professor A. W. CROSSLEY (*Secretary*), Professor W. H. PERKIN, Dr. M. O. FÖRSTER, *and* Dr. H. R. LE SUEUR.

Action of ethyl cyanoacetate on 5-*chloro*-1 : 1-*dimethyl*- Δ^4-*cyclohexen*-3-*one*.—The action of ethyl cyanoacetate on chlorodimethylcyclohexenone[1] might be expected, by analogy with the action of ethyl sodiomalonate on the same ketone,[2] to give rise to ethyl 1 : 1-dimethyl- Δ^4 -cyclohexen-3-one-5-cyanoacetate (I). But although the reaction product possesses this empirical formula, it has properties which are incompatible with those of a substance of this constitution, for it behaves as a monobasic acid, forming compounds by elimination of water with aniline and monomethylaniline, and giving esters when heated with alcohol containing 5 per cent. sulphuric acid. In the latter case two isomeric methyl or ethyl derivatives are produced. When hydrolysed with acids, both the original condensation product and either of its ethyl or methyl derivatives are transformed into trimethylcyclohexenone (II).

$$(CH_3)_2.C<\begin{array}{l}CH_2-CO\\CH_2-\underset{|}{C}\end{array}\!\!>CH \quad \text{(I)} \qquad (CH_3)_2C<\begin{array}{l}CH_2-CO\\CH_2-\underset{|}{C}\end{array}\!\!>CH \quad \text{(II)}$$
$$CN.CH.CO_2C_2H_5 \qquad\qquad\qquad\qquad CH_3$$

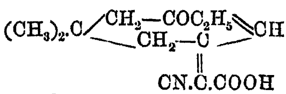
An explanation of the behaviour of the condensation product is afforded by adopting Thorpe's formula for ethyl sodiocyanoacetate,[3] when the reaction would be formulated in the following manner. The initial additive compound (III) would lose the elements of sodium chloride forming ethyl 1 : 1-dimethylcyclohexan-3-onylidene-5-cyanoacetate (IV) and by tautomeric change, ethyl 3-hydroxy-1 : 1-dimethyl- Δ^3-cyclohexenylidene-5-cyanoacetate (V).

$$(CH_3)_2C<\begin{array}{l}CH_2-CO\\CH_2-\underset{|}{C}Cl\end{array}>CH_2 \qquad (CH_3)_2C<\begin{array}{l}CH_2-CO\\CH_2-\underset{\|}{C}\end{array}>CH_2 \qquad (CH_3)_2C<\begin{array}{l}CH_2.COH\\CH_2-\underset{\|}{C}\end{array}>CH$$
$$CN.C:C(ONa).OC_2H_5 \qquad CN.C.CO_2C_2H_5 \qquad CN.C.CO_2C_2H_5$$
$$\text{(III)} \qquad\qquad \text{(IV)} \qquad\qquad \text{(V)}$$

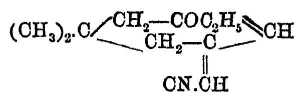
The last formula accounts for all the observed properties of the substance, including its ability to form two ethyl derivatives which can be represented as *cis* and *trans* modifications. When either of these ethyl derivatives is hydrolysed with potassium hydroxide in ethyl alcoholic solution, 3-ethoxy-1 : 1-dimethyl-Δ^3-cyclohexenylidene-5-cyanoacetic acid (VI) is produced, which on heating loses the elements of carbon

[1] Crossley and Gilling, *J.C.S.*, 1910, 97, 518.
[2] *Ibid.*, *J.C.S.*, 1909, 95, 19.
[3] *J.C.S.*, 1900, 77, 925.

dioxide with formation of 3-ethoxy-1 : 1-dimethyl-Δ^3-cyclohexenylidene-5-acetonitrile (VII).

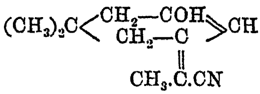


(VI)



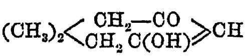
(VII)

Although somewhat stable towards alkali this nitrile is readily hydrolysed by acids with formation of 1 : 1 : 5-trimethyl-Δ^4-cyclohexen-3-one (II). When chlorodimethylcyclohexenone is condensed (*a*) with the sodium derivative of ethyl methylcyanoacetate, the product is hydroxydimethylcyclohexenylidenepropionitrile

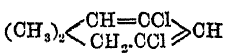


the carbethoxy group being eliminated as ethyl carbonate; (*b*) with ethyl sodioacetoacetate, the product is the same as with ethyl malonate, namely, ethyl dimethylcyclohexenoneacetate, ethyl acetate appearing as a by-product. The elimination in these reactions of ethyl carbonate and ethyl acetate respectively is probably governed by spatial considerations.

3 : 5-Dichloro-o-xylene and 3 : 5-dichlorophthalic acid.[1]—The main product arising from the action of phosphorus pentachloride on dimethyldihydroresorcin (I) is 3 : 5-dichloro-1 : 1-dimethylcyclohexadiene (II), but a by-product is also formed which was thought to be 3 : 5-dichloro-*o*-xylene (III).



(I)



(II)

(III)

This structure was assigned to the latter substance because there did not appear to be any reason to presume that, in the conversion of the hydroaromatic into the aromatic dichloro-derivative, the chlorine atoms would alter their positions. During the reaction, however, a methyl group must have wandered, and this was shown to have migrated to the ortho-position, because on oxidation an acid (3 : 5-dichlorophthalic acid) was obtained which readily gave an anhydride, and also the fluorescein reaction.

In a recent number of the 'Berichte'[2] Villiger described the preparation of three of the four possible dichloro-*o*-phthalic acids (Cl : Cl, 3 : 6, 3 : 4, 4 : 5) by the direct chlorination of phthalic anhydride. Villiger points out (*ibid.*, p. 3532) that a fourth isomeride was

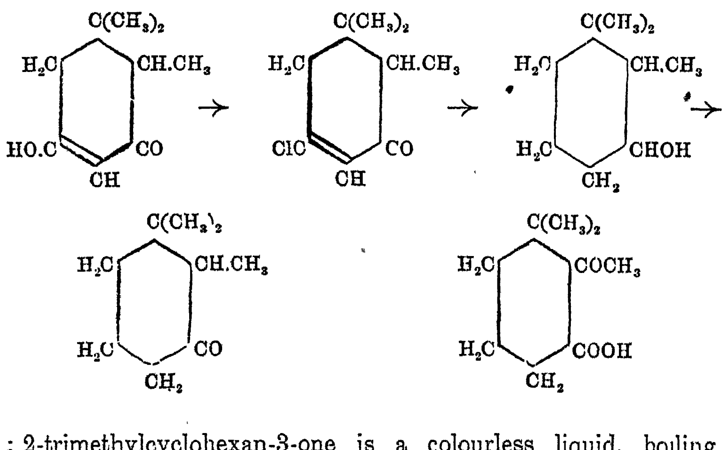
[1] Crossley and Wren, *J.C.S.*, 1910, 97, 98. [2] *Ber.*, 1909, 42, 3529

described by Crossley and Le Sueur in 1902,[1] and regards the acid as 3 : 5-dichloro-*o*-phthalic acid, although 'its constitution has never been controlled.'

3 : 5-dichloro-*o*-xylene has now been prepared from 3 : 5-dinitro-*o*-xylene by means of the diazo reaction, and oxidised to 3 : 5-dichlorophthalic acid. A detailed comparison of the properties of these synthetic products with those obtained as above mentioned from dimethyldihydroresorcin shows them to be identical, as seen from the following tabulated statement:—

	From dimethyldihydroresorcin.	From 3 : 5-dinitro-*o*-xylene.
Dichloroxylene	Yellow, refractive liquid; slight aromatic odour. B.p. 226°, m.p. 3–4°.	Yellow, refractive liquid; slight aromatic odour. B.p. 226°, m.p. 5–7°.
Dichlorodinitroxylene	M.p. 175–176°.	M.p. 176°.
Dichlorophthalic acid	M.p. 164° (previous softening) with evolution of gas.	M.p. 164° (previous softening) with evolution of gas.
Dichlorophthalic anhydride	M.p. 89°.	M.p. 89°.
Dichlorophthalanil	M.p. 150–150°·5.	M.p. 150°.

Hydro-aromatic ketones.[2]—In continuation of the work previously described[3] 1 :1 :2-trimethylcyclohexan-3-one has been prepared from trimethyldihydroresorcin as a starting point, the various steps involved being indicated by the following formulæ:—



(I)

1-1 : 2-trimethylcyclohexan-3-one is a colourless liquid, boiling at 190°/750 mm., and when oxidised with potassium permanganate yields δ-acetyl-δ-methylhexoic acid (I), which fact definitely establishes its constitution. The investigation of this ketone is being continued, partly on account of the similarity in the groupings which it contains with those of the camphor molecule.

[1] *Trans.*, 81, 1533.
[2] Unpublished work.
[3] Crossley and Renouf, *J.C.S.*, 1907, 91, 63.

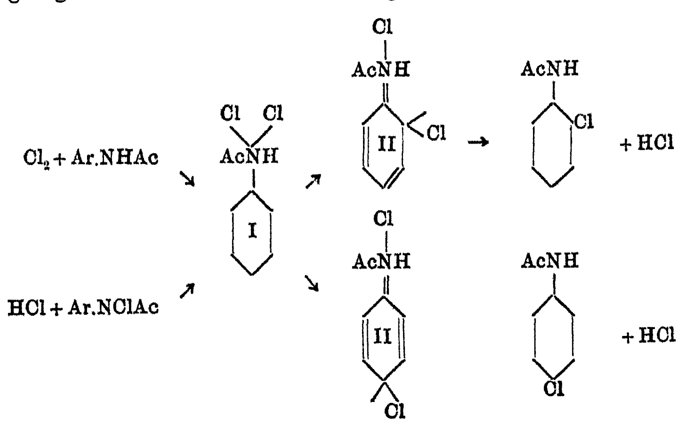
The Transformation of Aromatic Nitroamines and Allied Substances, and its Relation to Substitution in Benzene Derivatives.—Report of the Committee, consisting of Professor F. S. KIPPING (*Chairman*), Professor K. J. P. ORTON (*Secretary*), Dr. S. RUHEMANN, Dr. A. LAPWORTH, *and* Dr. J. T. HEWITT.

I.—*The Chlorination of Anilides and the Transformation of Acylchloroaminobenzenes.*

(*With* W. J. JONES, *B.Sc.*)

IN summarising his views on substitution in aromatic compounds, Armstrong[1] expressed the belief that in the formation of derivatives of anilines and phenols, the reagent united directly with the nitrogen or oxygen, the residual valency of these atoms coming into play. In the case of anilines and anilides the definite compounds, which can often be isolated, nitroamines, chloroamines, &c., were held by Armstrong to be 'a necessary stage in the formation' of the substituted aniline or anilide, the process of conversion being 'regarded as one of isomeric change.' He suggested further that, as part of the mechanism of the change, 'the centric benzene nucleus assumed momentarily the highly unstable ethenoid form.'

Later, Armstrong[2] discovered that the chloroaminobenzenes were only converted into the isomeric chloroanilides in the presence of hydrochloric acid. Blanksma[3] showed that under the conditions under which he worked the reaction was of the first order, and the speed proportional to the square of the concentration of the hydrogen chloride. It had been suggested by Orton[4] that all such isomeric changes of the N-substituted derivatives under the influence of an acid catalyst were due to the formation of a complex or salt (I) in which the nitrogen was quinquevalent. This compound was capable of undergoing an intra-molecular rearrangement, in which the benzene



[1] *Reports*, 1899.
[2] *Trans. Chem. Soc.*, 1900, 77, 1051.
[3] *Recueil des Trav. Chim.*, 1903, 22, 290.
[4] *Proc. Roy. Soc.*, 1902, 71, 156.

nucleus shared, assuming an *o*- or *p*-quinonoid form (II). The substituting group wandered in this rearrangement into the *o*- or *p*-position. Thus the rigid adherence of anilines and anilides to the ortho-para law was accounted for.

Subsequently Acree[1] adopted the formation of the complex as the cause of the arrangement of chloroamines, and showed how, on this assumption, the speed of the change is proportional to the square of the concentration of hydrochloric acid, for the concentration of the reactive complex is proportional to the square of the concentration of the hydrogen chloride if it be ionised, thus:—

$$\mathrm{Ar.NHAcCl_2} \rightleftarrows \mathrm{Ar.NClAc} + \mathrm{H^{\cdot}} + \mathrm{Cl'}.$$

The discovery (by Orton and Jones[2]) that an equilibrium existed between chloroamine, hydrogen chloride, anilide, and chlorine, thus: $K = [\text{chloroamine}]\,[\mathrm{HCl}] / [\text{anilide}]\,[\mathrm{Cl_2}]$; or, when the medium is 65 per cent. acetic acid, or more dilute

$$K^1 = [\text{chloroamine}]\,[\mathrm{HCl}]^2 / [\text{anilide}]\,[\mathrm{Cl_2}],$$

showed that other factors had to be taken into account. This equilibrium may be represented thus:—

$$\mathrm{Ar.NHAc} + \mathrm{Cl_2} \rightleftarrows \text{complex} \rightleftarrows \mathrm{Ar.NClAc} + \mathrm{HCl},$$

a relation which has been stated by Acree as a possibility. The facts of the case, however, do not appear to require in any way the existence of such an intermediary.

The discovery of the formation of free chlorine and anilide when hydrogen chloride reacts with chloroamine has led us to a new investigation of the transformation of chloroamines, and of the process of halogenation of anilides.

The Catalyst.—A great difficulty in the way of the 'complex hypothesis' is the fact that hydrochloric acid alone has the power of bringing about the isomeric change of the chloroamine. Acree believed that other acids, and even chlorine and bromine, were similarly, but less powerfully, effective. But although we have examined this point very closely we have not been able to confirm his view.

In dilute acetic acid, when no hydrochloric acid has been added, the change of the chloroamine occurs at first slowly, but gathering speed. Hydrogen chloride can always be detected. Thus in 65 per cent. acetic acid after half the chloroamine (initial concentration 0·025 gram-molecule per litre) has disappeared $\frac{1}{16}$ of the chlorine initially present in the chloroamine is found as hydrogen chloride.

The addition of sulphuric acid (nitric, perchloric, or hydrofluoric acid) somewhat increases the rate of change, some 10 per cent. of the chlorine appearing as hydrogen chloride during the first half of the reaction.

The action of halogens was tested in carbon tetrachloride solution. (Obviously petroleum, which was used by Acree, is unsuitable for such experiments.) With acetanilide, chlorine reacts instantaneously

[1] *Amer. Chem. Journ.*, 1907, 38, 258.
[2] *Trans. Chem. Soc.*, 1909, 95, 14; *Reports*, 1909.

in this solvent, the insoluble *p*-chloro-derivative separating immediately. With the chloroamine there is no immediate reaction, then after an interval, extending occasionally to days, a change begins, which finally attains considerable speed (Diagram I. fig. 2); crystals of *p*-chloroacetanilide appear as soon as saturation for this substance is reached. If the quantity of chlorine suffices, further chlorination of this compound, and still more, of the soluble *o*-chloro-derivative which is produced simultaneously, follows.

In both reactions the halogen attacks either a minute quantity of anilide present with the chloroamine, or, more probably, a trace of some impurity, yielding hydrogen chloride or bromide, which then reacts with the chloroamine. In carbon tetrachloride it has been shown (by the aspiration-method) in the case of anilides which do not chlorinate, that the reaction, $Ar.NClAc+HCl=Ar.NHAc+Cl^2$, is quantitative.

In the case of bromine the reactions are (after the formation of a trace of hydrogen bromide):—

$$Ar.NClAc + HBr = Ar.NHAc + BrCl = BrAr.NHAc + HCl;$$
$$Ar.NClAc + HCl = Ar.NHAc + Cl_2;\ Cl_2 + Br_2 = 2BrCl.$$

Bromine chloride has been shown to be stable in carbon tetrachloride and other anhydrous solutions, and to be a most powerful brominating agent of anilides. The reactions proceed until the bromide is exhausted, when chlorination begins.

These experiments show further that chloroamines cannot be directly chlorinated or brominated.

Comparison of the Direct Action of Chlorine on Anilides with the Conversion of Chloroamines in the Presence of Hydrochloric Acid.

1. In glacial acetic acid the two processes, chlorine on anilide and hydrochloric acid on chloroamine, give an identical rate of chlorination. It is a reaction of the second order, for acetanilide $k_{II}=40$, and for *p*-chloroacetanilide $k_{II}=0{\cdot}21$. In glacial acetic acid the equilibrium, $Ar.NHAc+Cl_2 \rightleftarrows Ar.NClAc+HCl$, gives an inappreciable amount of chloroamine and hydrochloric acid.

The effect of small quantities of water is to accelerate the chlorination in a direct ratio. But after the addition of 4 to 5 per cent. the water begins to affect the equilibrium and favours the production of chloroamine and hydrochloric acid.

The speed of chlorination when the system is made up of chloroamine and hydrochloric acid still continues to increase, but as the curve I. shows, only to a composition of the medium 92 per cent. acetic acid, when the speed begins to decrease. Curves II. and III. show respectively the falling-off in two systems in the amount of chlorine and anilide with dilution of the acetic acid.

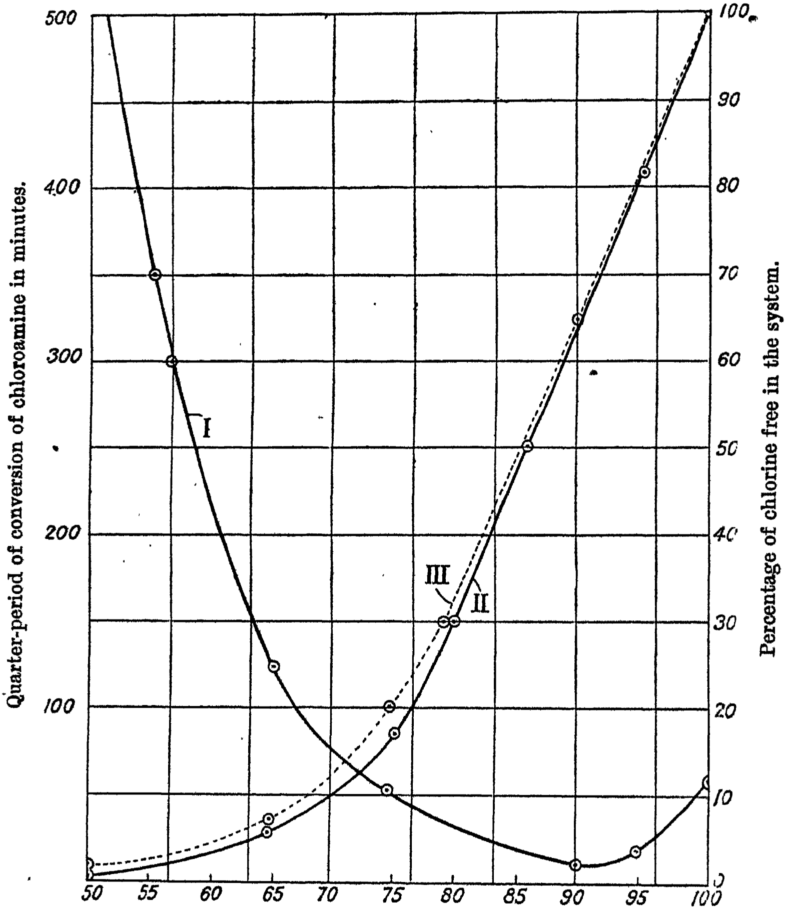
2. In dilute acetic acids the rate of formation of C-chloro-derivatives is very different in the two cases. On bringing together anilide and chlorine a very rapid formation of both C-chloro- and N-chloro-derivative occurs, a very small proportion of the chlorine (measured by aspiration) remaining free in the system. The relative proportions of the two compounds, which vary with the anilide and the composition of the medium, is shown in Table I.

DIAGRAM I.—FIG. 1.

I. = Change in quarter-period of conversion of acetylchloroamino-*p*-chlorobenzene with concentration of the acetic acid medium.

II. = Cl_2 + *p*-chloroacetanilide.

III. = Cl_2 + 2 : 4-dichloroacetanilide.



Medium, expressed as percentage of acetic acid by volume

DIAGRAM I.—FIG. 2.

IV. = Cl_2 + chloroamine.
V. = Br_2 + chloroamine.

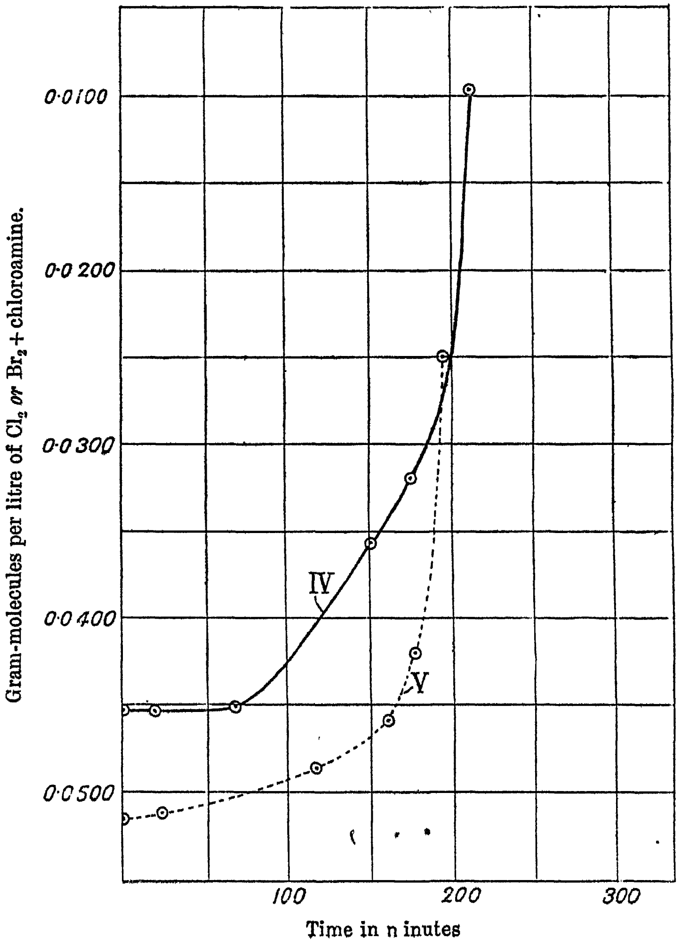


TABLE I.

Ratio of $\frac{\textit{Chloroamine}}{\textit{Chloroanilide}}$ *from Interaction of Chlorine and Anilide.* $T = 15°$.

Medium. Percentage Acetic Acid (by Volume)	Acetanilide	*p*-Chloroacetanilide
0	0·07/1	—
30	0·082/1	0·93/1
50	0·08/1	1·25/1
65	0·083/1	1·55/1

The N-chloro-derivative slowly disappears and is replaced by the chlorinated anilide.

The conversion of the chloroamine in the presence of hydrochloric acid, on the other hand, is a slow, regular, apparently monomolecular reaction, the speed of which is, in dilute (below 50 per cent.) acetic acid, proportional to the square of the concentration of the hydrochloric acid. Table II. shows, however, that this relation only holds within narrow limits.

TABLE II.

Medium	Acetylchloroaminobenzene Conc. 0·025			Acetylchloroamino-*p*-chlorobenzene Conc. 0·025		
Dilute Acetic Acid	Conc. HCl	k_1	n	Conc. HCl	k'_1	n
50 per cent.	0·025	0·00039	1·94	0·025	0·00053	1·36
	0·05	0·0015		0·050	0·00135	1·33
65 per cent	0·025	0·0026	1·60	0·025	0·0023	1·43
	0·05	0·0078		0 05	0·0062	
75 per cent.	0·025	0·0126	1 70	0·075	0·0093	1·27
	0·05	0·43				

Under 'n' is given the values from the equation

$$\frac{k}{k'_1} = \frac{\text{HCl}^n}{\text{HCl}'^n};$$

whence

$$n = \log \frac{k}{k'_1} \bigg/ \log \frac{\text{HCl}}{\text{HCl}'}.$$

Further, the apparently monomolecular character of the reaction is not maintained throughout the change. The product, the chlorinated anilide, even when incapable of further chlorination, exerts a disturbing influence causing a decrease of the rate. This is well shown in the case of *p*-chloroacetylchloroaminobenzene, which yields 2 : 4-dichloroacetanilide.

Experiment A.—*p*-chloroacetylchloroaminobenzene = 0·025 gm. mol. per litre. HCl = 0·025 gm. mol. Medium, 65 per cent. acetic acid.

TABLE III.

Time (in Minutes) . . .	128	213	300	407	590	758	954
Percentage of chloroamine converted	26 2	39·1	48·5	57·2	67·4	73·2	78·2
k_1	0·0027	0·0023	0·0017	0 0017	0 0015	0·0012	0·001

Experiment B.—As in experiment A, but in addition 1 gm. mol. proportion of 2 : 4-dichloroacetanilide.

TABLE IV.

Time (in Minutes) .	18	100	301	428	687	826	1096
Percentage of chloroamine converted	1·72	7·8	21 2	32·1	41·1	45·4	54 8
k_1	0 0007	0·0007	0·00076	0·00078	0·00076	0·00072	0·00072

In order to understand more fully the influence of the anilide which is produced on the conversion of the chloroamine, the effect of the presence of a second anilide on the equilibrium between chlorine and anilide must be considered.

Equilibrium between Chlorine and Anilide in Systems containing more than one Anilide.

If one gram molecular proportion of an anilide, B, is added to a system prepared from one molecular proportion of chloroamine of anilide A, and one molecular proportion of hydrochloric acid, a rapid readjustment occurs to a final equilibrium which is in accord with the two equations:—

$$[\text{Chloroamine A}][\text{HCl}]^2/[\text{Anilide A}][\text{Cl}_2] = K_A.$$

$$[\text{Chloroamine B}][\text{HCl}]^2/[\text{Anilide B}][\text{Cl}_2] = K_B.$$

Since $[\text{Cl}_2]$ and $[\text{HCl}]^2$ are identical in the two equations, we have:—

$$\frac{\text{Chloroamine A}}{\text{Anilide A}} \cdot \frac{\text{Chloroamine B}}{\text{Anilide B}} = K_A/K_B.$$

In 65 per cent. acetic acid, the $[\text{Cl}_2]$ is generally negligible, and hence the relative amounts of each anilide and chloroamine can be easily calculated. When the $[\text{Cl}_2]$ has an appreciable value, the calculations of the composition of the system involves the solution of a quintic equation.

In 90 per cent. acetic acid and above the equilibrium equation contains the first instead of the second power of the concentration of the hydrochloric acid, and the calculation of the composition is by means of a cubic equation which has been solved. Thus in a system made up from molecular proportions (0·025 gm. mol. per litre) of *s*-tribromoacetanilide, hydrochloric acid and acetylchloroamino-*p*-nitrobenzene (or, from *p*-nitroacetanilide, hydrochloric acid and acetyl-

chloroamino-s-tribromobenzene), 59 per cent. of the chlorine originally as chloroamine was found to be free, whilst 60 per cent. was the amount calculated. For comparison in the system prepared from s-tribromoacetanilide and chlorine, the free chlorine is 57 per cent., whilst in that prepared from p-nitroacetanilide and chlorine, the free chlorine is 89 per cent.

In the case of p-chloroacetanilide and 2 : 4-dichloroacetanilide quoted above, where the value of K (in 65 per cent. acetic acid) for the former is 8·1 and for the latter 4·47, it is calculated that in the system when half the chloroamine has been converted into 2 : 4-dichloroacetanilide, the concentrates of the anilides and chloroamines are as follows:—

$$[p\text{-}Cl.C_6H_4.NClAc] = [2 : 4\text{-}Cl_2.C_6H_3.NHAc] = 0{\cdot}0072,$$
$$[p\text{-}Cl.C_6H_4.NHAc] = [2 : 4\text{-}Cl_2.C_6H_3.NClAc] = 0{\cdot}0053;$$

that is the concentration of the chloroamine, which is changing, is 0·0072 instead of 0·025/2 = 0·0125.

Chlorination of an Anilide by the Chloroamine of another Anilide.

The chloroamine of such an anilide as 2 : 4-dichloroacetanilide is in the presence of hydrochloric acid a chlorinating agent for acetanilide. Thus in 65 per cent. acetic acid rapid chlorination follows the addition of a gram molecular proportion of acetanilide to gram molecular proportions of the chloroamine and hydrochloric acid (where 6 per cent. of the chlorine is free). The chlorination is far more speedy, $k_1 = 0{\cdot}42$, than in the transformation of acetylchloroaminobenzene, $k_1 = 0{\cdot}0026$.

In 50 per cent. acetic acid, where a far smaller percentage of chlorine is free, $k^1 = 0{\cdot}00039$ for the transformation of the chloroamine, and 0·01 for the action of the chloroamine on the anilide.

Measurement of the speed of the Opposing Reactions in the Equilibrium:
k_{II} [Ar.NHAc] $[Cl_2]$ = k_{III} [Ar.NClAc] $[HCl]^2$.

Since the action of chlorine on acetanilide is very rapid the chlorination of acetanilide by a chloroamine and hydrochloric acid gives a means of determining the value of the co-efficient k_{III} and since k_{II}/k_{III} is known also the value of k_{II}. When the concentration of acetanilide is so large that the velocity of the chlorination is not increased by further rise in the concentration of the acetanilide, it is obvious that the speed of the total change is controlled by that of the interaction of the chloroamine and hydrochloric acid, the slowest step in the series. That is the speed of the chlorination $= k_{III}$ [chloroamine] . $[HCl]^2$. The chloroamine alone varies in concentration, hence the velocity of the reaction is expressed by an equation of the first order. For two determinations of the amount of chloroamine, p and q, at times t and t_0, we have therefore:—

$$k_{III}[HCl]^2 = \frac{1}{t - t_0} \cdot \log e \frac{p}{q} = \lambda;$$

or

$$k_{III} = \lambda / [HCl]^2.$$

The values of k_{II} and k_{III} are shown for a number of anilides in the following table (V.).

TABLE V.

Anilide	Medium. Dilute Acetic Acid	k_{III}	K	k_{II}
p-nitroacetanilide . .	50 per cent.	109	—	—
p-chloroacetanilide .	50 per cent.	4·6	—	—
p-chloroacetanilide .	65 per cent.	22	8·1	178·2
2 : 4-dichloroacetanilide	50 per cent.	15 5	[69·8 ?]	[1,081 ?]
2 : 4-dichloroacetanilide	65 per cent	91	4 47	406 8

The Interaction of Acetanilide with Acetylchloroamino-p-chlorobenzene and Hydrochloric Acid.

The effect of the presence of an anilide on the conversion of the corresponding chloroamine—for example, of acetanilide on the conversion of acetylchloroaminobenzene, or of *p*-chloroacetanilide on that of the acetylchloroamino-*p*-chlorobenzene—is small. In the first instance, owing to the equilibrium, the concentration of the chloroamine is increased and that of free chlorine reduced. But in 50 per cent., or even in 65 per cent., acetic acid, the proportion of free chlorine and anilide is so small that relatively little alteration of concentration of the chloroamine is brought about, but the alteration in the chlorine is considerable. Thus, taking as an example the system made up from *p*-chloroacetanilide and chlorine, the proportion of free chlorine is 0·4 and 5·3 per cent. in 50 and 65 per cent. acetic acid respectively, but on adding one molecular proportion of the anilide this drops to about 0·2 per cent. in the latter medium. The velocity of chlorination increases in the ratio 1·19/1 in 50 per cent., and in the ratio 1·22/1 in 65 per cent. With acetanilide, where the proportion of free chlorine is somewhat less, the ratio of the velocities is 1·13/1.

When acetanilide and the chloroamine of *p*-chloroacetanilide interact in the presence of hydrochloric acid the result is very remarkable and instructive. The acetanilide is alone chlorinated; the amount of 2:4-dichloroacetanilide is insufficient to admit of detection. On comparing the velocities the remarkable character of the reaction is made more clear. In 50 and 65 per cent. acetic acid the reactions are of the first order. (Diagram II., figs. 3 and 4.)

TABLE VI.

—	k_I in 50 per cent.	k_I in 65 per cent.
p-$Cl.C_6H_4.NClAc + HCl \rightarrow$ 2 : 4-$Cl_2.C_6H_3.NHAc$	0·00053	0 0023
$C_6H_5.NClAc + HCl \rightarrow$ *o*- and p-$Cl.C_6H_4.NHAc$	0·00039	0·0026
p-$Cl.C_6H_4.NClAc + HCl + C_6H_5.NHAc \rightarrow$ *o*- and p-$Cl.C_6H_4.NHAc$	0 0016	0·0092

In both media the speed of chlorination of acetanilide by the chloroamine of *p*-chloroacetanilide is far more rapid than the conversion of the chloroamine of acetanilide into the isomeride. In 50 per cent. acetic acid the conversion of acetylchloroamino-*p*-chlorobenzene is faster than that of acetylchloroaminobenzene. Although the experiments on the changes occurring when an anilide is added to a mixture

DIAGRAM II.—FIG. 3.

$-dx/dt$ curves in 50 per cent. acetic acid.

I. = C_6H_5.NClAc + HCl. II. = p-ClC_6H_4.NClAc + HCl.
III. = C_6H_5 NHAc + p-ClC_6H_4.NClAc + HCl.

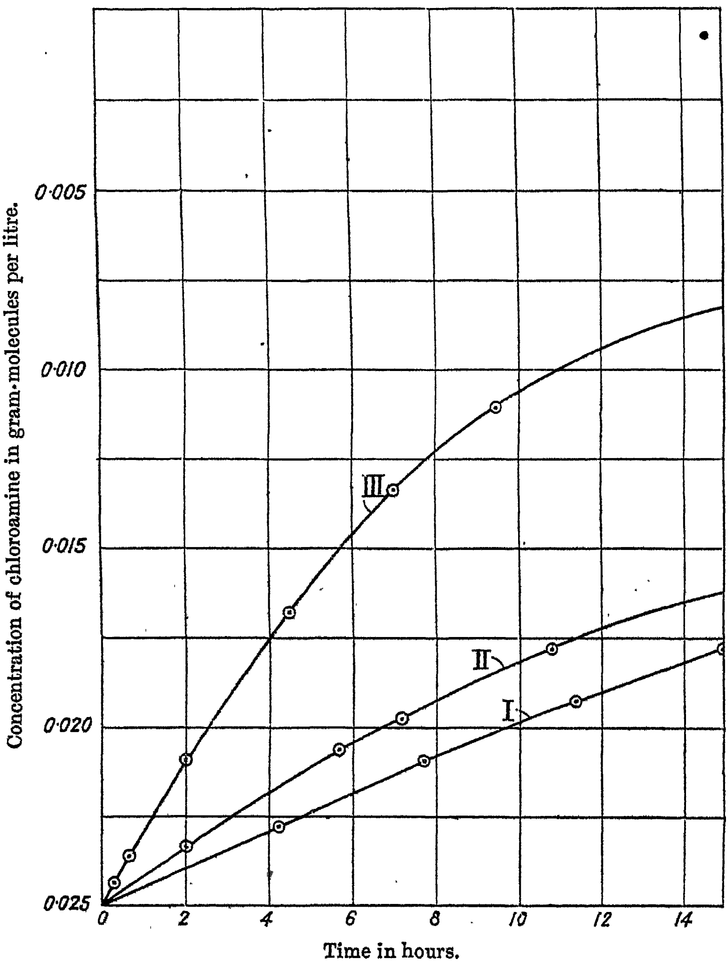
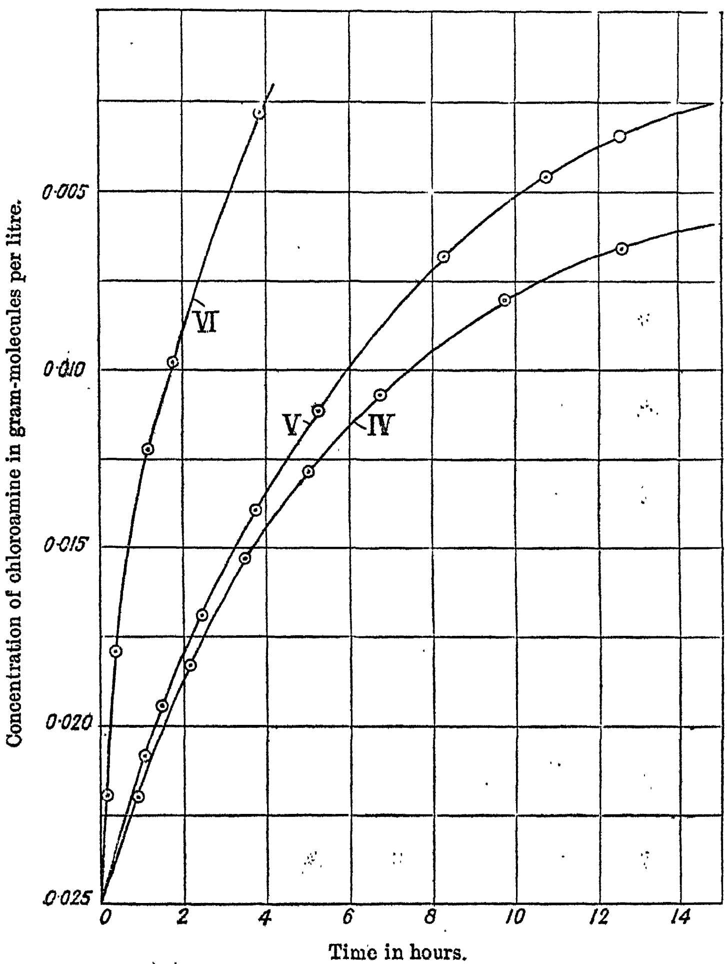


DIAGRAM II.—FIG. 4.

$-dx/dt$ curves in 65 per cent. acetic acid.

IV. $= p\text{-}ClC_6H_4.NClAc + HCl$. V. $= C_6H_5.NClAc + HCl$
VI. $= p\text{-}ClC_6H_4.NClAc + C_6H_5.NHAc + HCl$.



of the chloroamine of another anilide and hydrochloric acid, show that in this case the chloroamine of acetanilide may be formed, yet the relation of the velocities of the C-chlorination in the various systems make it impossible for the chlorination of the acetanilide to take place by way of the chloroamine. If that were the route, the process could not be faster than when the starting-point was the chloroamine of acetanilide. Further, when on the other hand the chloroamine of acetanilide and hydrochloric acid interact with *p*-chloroacetanilide in 50 per cent. acetic acid, a slow chlorination occurs, and, in spite of the difficulty of isolating small quantities of 2:4-dichloroacetanilide from such a mixture, its presence was undoubtedly demonstrated by the isolation of the pure material; that is, some chlorination of *p*-chloroacetanilide took place.

Mechanism of Chlorination (and Bromination) and of the Conversion of Chloroamines.

The experiments recorded in the foregoing leave no doubt that the chloroamines cannot be regarded as even occasional intermediaries, much less necessary intermediaries in chlorination. They would rather appear to be by-products.[1]

The residual valency of the nitrogen atom was urged by Armstrong as the prime factor in bringing about the initial union of the substituting agent and the anilide. Such a substance would be, in chlorination, the compound, $Ar.NHAcCl_2$, identical with the complex formed from chloroamine and hydrochloric acid, already referred to.

If the existence of this reactive complex be assumed, our experiments enable one to deduce a number of its properties.

(i) The action of chlorine on acetanilide and *p*-chloroacetanilide in various dilutions of acetic acid, show that the rate of formation and of change of the complex into the substituted anilide must increase rapidly with dilution of the acetic acid.

(ii) The concentration of the complex (in any case minute) must rapidly decrease with dilution of the acetic acid medium, in a system which has attained equilibrium, since the velocity of C-chlorination in a system prepared from chloroamine and hydrochloric acid decreases with the dilution.

(iii) Inasmuch as the rate of C-chlorination in diluted acetic acid is so markedly faster when chlorine and anilide are allowed to interact than when the system is prepared from chloroamine and hydrochloric acid, the rate of change of the complex into a C-chloro-derivative must be greater than into the N-chloro-derivative:—

$$Ar.NHAcCl_2 \begin{cases} \xrightarrow{\text{slow}} Ar.NClAc + HCl. \\ \xrightarrow[\text{fast}]{} ClAr.NHAc + HCl. \end{cases}$$

[1] They can only be regarded as intermediaries when hypochlorous acid acts on an anilide, for then the chloroamine only and no C-chloro-derivative is formed. Introduction of hydrogen chloride is required, however, for the conversion of the chloroamine into the C-chloro-compound.

On the other hand, in acetic acid of high concentration, 90 to 100 per cent., the rate of change of the complex into chlorine and anilide must be much faster than into chlorinated anilide:—

$$\mathrm{Ar.NHAcCl_2} \begin{cases} \xrightarrow{\text{slow}} \mathrm{ClAr.NHAc + HCl} \\ \xrightarrow[\text{fast}]{} \mathrm{Cl_2 + Ar.NHAc}; \end{cases}$$

for the rate of C-chlorination is the same whether the system is made up from chloroamine and hydrogen chloride or from chlorine and anilide.

(iv) The complex formed from acetanilide may be compared with that formed from *p*-chloroacetanilide. Since the speed of chlorination of acetanilide is very much greater (200 times in glacial acetic acid) than that of *p*-chloroacetanilide, the rate of formation of the complex from acetanilide and of its transformation are the more rapid. Nevertheless in dilute acetic acid, 50 per cent., the rate of conversion of acetylchloroaminobenzene ($k_1 = 0{\cdot}00039$) is slower than that of acetylchloroamino-*p*-chlorobenzene ($k_1 = 0{\cdot}00053$); hence it must be assumed that the complex is produced at a slower rate from hydrogen chloride and acetylchloroaminobenzene, or, what would have the same effect, its concentration is very much smaller than in the case of *p*-chloroacetanilide. Moreover, the contrast is emphasised by the fact that the speed of chlorination of acetanilide by the chloroamine of *p*-chloroacetanilide is relatively high. Here it must be assumed that the very fast formation (and rearrangement) of the compound of acetanilide and chlorine, the latter being set free by the reactions

$$p\text{-}\mathrm{Cl.C_6H_4.NClAc + HCl \rightarrow Cl.C_6H_4NHAcCl_2} \begin{cases} \xrightarrow{\text{slow}} \mathrm{Cl_2.C_6H_3NHAc + HCl} \\ \xrightarrow[\text{fast}]{} \mathrm{Cl.C_6H_4.NHAc + Cl}, \end{cases}$$

keep the concentration of the compound, $\mathrm{Cl.C_6H_4.NHAcCl_2}$, at vanishing point and thus prevent the formation of 2:4-dichloroacetanilide.

Alternative Hypothesis. Direct Action of Halogen on Anilide or on a Dynamic Isomeride.

It may well be asked whether the facts of chlorination and the transformation of the chloroamines require for their interpretation the assumption of the existence of a complex with many-sided characters and capable of undergoing an intramolecular rearrangement in which the wandering group is a chlorine atom.

The specific part played by the hydrogen chloride in the transformation of the chloroamine, and the fact that this reagent causes the production of chlorine and anilide, and the results of numerous experiments, which may be summarised in the statement—whenever chlorine and anilide are present at maximum concentration the speed of chlorination is highest—are more, or at least as, simply accounted for by direct interaction of chlorine and anilide.

An example may be found in the relation between the rate of conversion of the chloroamine and the concentration of the hydrogen

chloride. Blanksma showed for acetylchloroaminobenzene that the reaction was of the first order, and the velocity proportional to the square of the concentration of the hydrogen chloride. Assuming the conversion to be due to the setting free of chlorine and anilide followed by direct chlorination, then

$$d[\text{chloroanilide}]/dt = k_{II}[\text{anilide}][Cl_2].$$

But

$$K[\text{anilide}][Cl_2] = [\text{chloroamine}][HCl]^2;$$

hence

$$d[\text{chloroanilide}]/dt = k_{II}[\text{chloroamine}][HCl]^2/K$$

[chloroamine] equals approximately the chloroamine originally present, when the amount of anilide and chlorine in the system in equilibrium is very small, as in the case in media below 50 per cent. acetic acid. [HCl] is constant. Hence

$$d[\text{chloroanilide}]/dt = k_{II}.\text{Const.}[\text{chloroamine}]/K = k'[\text{chloroamine}],$$

a reaction of the first order.

But it still remains to suggest causes for the extraordinary reactivity of anilides towards substituting agents and their rigid adherence to the ortho-para law. The hypothesis may be put forward that the constitution of anilines and anilides, similar to but in a less degree than *p*-nitrosophenol, permits of the passage into a dynamic isomeride of quinonoid structure, which is accompanied by the wandering of hydrogen of the imino group to the *o*- or *p*-position. It is this isomeride which is reactive. The almost exclusive occurrence of *o*- and *p*-quinonoid compounds accounts for the position taken up by the substituting group. Just as with the hypothetical intermediary complex, a change of structure of the benzene nucleus is assumed; but here the mobile hydrogen atom and not chlorine migrates.

Further, this suggestion brings out the close analogy of the anilines and anilides with the phenols, where there is little evidence for the formation of compounds of the substituting agent with the oxygen, and much other evidence for the occurrence of a quinonoid structure.

This suggestion, on the other hand, relegates to the background the attractive view of the part played by the latent valency of the tervalent nitrogen, which permits of a ready means of primary union between the substituting agent and the anilide.

Flürscheim [1] has attempted to account for the laws of substitution in aromatic compounds by reference to latent or rather partial valencies of certain of the carbon atoms in a monosubstituted derivative of benzene; with certain substituents the attractions on the hydrogen atoms in the *o*- and *p*-positions, and with others in the *m*-position, are loosened, and hence more readily resubstituted. It is obvious that this view is independent of intermediate compounds, and would harmonise generally with the facts of chlorination as recorded in the foregoing.

Recently Lowry [2] has discussed this subject, and has suggested

[1] *Journ. Prakt. Chem.*, 1905, [2], 71, 497; *ibid.*, 1907, [2], 76, 165.
[2] *Science Progress*, 1909, 3, 616; 4, 213.

various ways in which the facts may be accounted for. He points out that the migrating group is always present in the system, whenever isomeric change is taking place.

II.—*Bromination of Anilides and the Conversion of Bromoamines.* (*With* W. J. Jones, *B.Sc.*)

The interaction between bromoamines and hydrobromic acid only differs in degree from that between chloroamines and hydrochloric acid. Tintometric measurements have shown that in acetic acid of all dilutions the reaction is quantitatively

$$Ar.NBrAc + HBr = Ar.NHAc + Br_2.$$

The direct bromination of the anilide is therefore always identical with the conversion of a bromoamine under the influence of hydrobromic acid.

The bromination which results when a chloroamine is treated with hydrogen bromide (or a bromoamine with hydrogen chloride) is a far more rapid process. In both these cases bromine chloride is formed and is the brominating agent.

Bromination, however, differs in one respect very markedly from chlorination in that hydrobromic acid and bromide exert a powerful retarding influence. Thus in the presence of four molecular proportions of hydrobromic acid, bromine does not act on acetanilide in glacial acetic acid at 16°. Hydrochloric acid, even when present at 8 to 10 times the concentration of the chlorine, has a scarcely perceptible effect.

The bromide exerts its maximum effect in glacial acetic acid. Addition of water reduces the effect, and as Fries [1] has shown, dilute acetic acid is the best medium for bromination of anilides. Thus in one of our experiments, in 75 per cent. acetic acid, using the molecular ratio, $8HBr : Br_2 : C_6H_5.NHAc$, three-quarters of the acetanilide was brominated in twenty minutes. *p*-Chloroacetanilide in glacial acetic acid is brominated too slowly for easy measurement; in 50 per cent. acetic acid, $k_{II} = 0·36$, and in water $= 12$.

The cause of this influence lies in the union of the bromine with bromidion forming Br'_3. We have shown by the method of aspiration that in glacial acetic acid, when bromine and hydrobromic acid are in molecular proportions, 75 per cent. of the bromine is combined with bromidion, but as the acetic acid is diluted the percentage of free bromine rapidly increases. In water we obtained by our method for the equilibrium, $K = [Br_2]\ [Br'] / [Br'_3]$, values similar to those found by Jakowkin [2] (by measurement of the distribution ratio between water and carbon tetrachloride); our value for $K^{15°}$ is 0·62, and Jakowkin's $K^{25°} = 0·63$.

[1] *Annalen*, 1906, **346**, 128.

[2] *Zeit. Phys. Chem.*, 1896, **20**, 38.

The Study of Isomorphous Sulphonic Derivatives of Benzene.—Report of the Committee, consisting of Principal MIERS (*Chairman*), *and* Professors H. E. ARMSTRONG (*Secretary*), W. J. POPE, *and* W. P. WYNNE.

IN the previous report it is pointed out that a clue to the interpretation of the results put forward in earlier reports had been found in the theory correlating molecular structure with crystalline form recently advanced by Messrs. Barlow and Pope.

During the past year the results obtained by the examination of twenty-nine derivatives of the 1 : 4 series have been discussed from the point of view of this theory and found to be in complete accordance with it. The investigation is published in two papers printed in the current August number of the 'Transactions of the Chemical Society.' It is hoped that the examination of the ortho- and meta- series will be completed during the coming year and that it will then be possible to summarise the results of the inquiry in a final report.

Erratic Blocks of the British Isles.—Report of the Committee, consisting of Mr. R. H. TIDDEMAN (*Chairman*), Dr. A. R. DWERRYHOUSE (*Secretary*), Dr. T. G. BONNEY, Mr. F. M. BURTON, Mr. F. W. HARMER, Rev. S. N. HARRISON, Dr. J. HORNE, Mr. W. LOWER CARTER, Professor W. J. SOLLAS, *and* Messrs. WM. HILL, J. W. STATHER, *and* J. H. MILTON.

REPORTS have been received during the year from three districts, in each case through a local Society: The University of Durham Philosophical Society, per Dr. Woolacott; the Hull Geological Society, per Mr. J. W. Stather, F.G.S., and the Belfast Naturalists' Field Club, per Miss Mary K. Andrews.

NORTHUMBERLAND AND DURHAM.

Reported by the BOULDERS COMMITTEE of the University of Durham Philosophical Society.

(1) *Reported by* DR. WOOLACOTT.

(*a*) Old sand-pit, North Moor Lane, Silksworth, near Sunderland:—

Volcanic series of Borrowdale. Cheviot porphyrite. Several granites. Coal. Magnesian limestone (numerous).

(*b*) Sand-pit near Bainbridge Holme Farm, Durham Road, near Sunderland:—

Whin Sill. Greywacke. Volcanic series of Borrowdale. Magnesian limestone.

(c) Lying loose, Galley Gill plantation, Silksworth:—
Coarse porphyrite.

(d) Gravel and sand-pit, Haverley House, near Seaton:—
Flint.

(e) Lying loose, Stotfold, near Seaton:—
Whin Sill. Granite.

(f) Boulder clay, Salterfen Rocks, coast south of Sunderland:—
Volcanic series of Borrowdale.

(g) Boulder clay, Carley Hill, near Sunderland:—
Volcanic series of Borrowdale. Greywacke.

(h) On the shore, Beadnell:—
Large boulder of Trachyte.

(i) Boulder clay, Kenton Quarries, near Newcastle:—
Threlkeld 'granite.' Cheviot granite. Cheviot porphyrite.

(2) *Reported by* Dr. Smythe *and* Dr. Woolacott.

(a) Lying loose, west of Seaton Station:—
Coarse agglomerate (1 cubic foot). Basalt. Coarse granite.

(b) Lying loose, near Sharpley Hall, Seaton:—
Threlkeld 'granite' (6 cubic feet). Sandstone. Whin Sill. Volcanic series of Borrowdale. Carboniferous limestone.

(c) Lying loose, end of Green Lane, Sharpley Plantation, Seaton:—
Whin Sill. Volcanic series of Borrowdale (3).[1] Greywacke. Granite, grey. Threlkeld 'granite' (2 cubic feet). Sandstone.

(d) Lying loose, Great Eppleton Plantation, near Warden Law:—
Rhyolite.

(e) Old gravel-pits, south-west of Warden Law:—
Greywacke (several). Chert. Sandstone. Granite. Porphyrite. Volcanic series of Borrowdale. Magnesian limestone. Carboniferous limestone.

(3) *Reported by* A. Bell, Bishop Auckland.

(a) Byers Green, Boulder clay, north-east of Bishop Auckland:—
Grey granite (Criffel). Volcanic series of Borrowdale.

(b) Near River Gaunless, a mile south-east of Bishop Auckland:—
Shap granite. Volcanic series of Borrowdale.

[1] The numbers placed after some of the specimens refer to number of specimens of that rock noted. The size of the specimen is given wherever it is noteworthy.

(4) *Reported by* G. WEYMAN.

(*a*) Boulder clay, Stob Hill, near Harlow Hill:—

Volcanic series of Borrowdale.

(*b*) Boulder clay, Kenton Quarries, near Newcastle:—

Grey. granite (Criffel). Threlkeld 'granite.' Volcanic series of Borrowdale. Calcareous grit. Red granite. Quartz porphyry (Cheviots). Andesite. Diorite. Volcanic series of Borrowdale (rhyolite and agglomerate). Schist (2).

(*c*) Gravel pit, Cleadon:—

Magnesian limestone (bored by marine organisms). Volcanic series of Borrowdale (rhyolite, 2). Porphyrite (Cheviots). Flint (3). Greywacke (2). Threlkeld 'granite.' Mica porphyrite (Cheviots). Buttermere syenite. Quartzite. Weathered Whin. Red Carboniferous limestone. Magnesian limestone breccia and several igneous rocks of doubtful origin (4 syenites), &c.

(5) *Reported by* E. MERRICK.

(*a*) Swinburne's clay-pit, Birtley:—

Armboth Dyke. Granite (grey).

(*b*) Billy Mill Quarry, near North Shields:—

Grey Granite.

(*c*) Prestwick Clay Pit, 1½ mile south-east of Ponteland:—

Quartz felsite. Volcanic series of Borrowdale. Greywacke.

(6) *Reported by* DR. SMYTHE.

(*a*) Gravel deposit, Horsebridge Head, near Newbiggin:—

Piece of Magnesian limestone with Fenestella retiformis.

(*b*) Boulder clay, Kenton Quarry, near Newcastle:—

Gabbro (Carrock Fell).

(*c*) Boulder clay, Horsebridge Head, mouth of Wansbeck:—

Mica andesite and felsite.

(*d*) Boulder clay, Hebron:—

Quartz porphyry.

(*e*) Hadston Carrs, south of Amble:—

Dolerite. Porphyrite. Magnesian limestone.

(*f*) Erratic (10 cubic feet), South Charlton:—

Augite granite (Cheviot).

(*g*) Kaims, near North Charlton:—

Greywacke. Granite. Syenite. Porphyrite.

(*h*) Kaims, Bradford, near Belford:—

Syenite (8). Greywacke. Quartz felsite. Andesite.

(*i*) Kaims, Fenrother, north-west of Morpeth:—

Greywacke (6). Syenite (4). Granite (4). Porphyrite (6). Andesite (2). Mica porphyrite (2). Quartzite.

(*j*) Boulder clay, Font, above Mitford:—

Syenite (7). Granite (6). Porphyrite (2). Andesite.

(*k*) Kaims, Loansdene Hill, near Morpeth:—

Greywacke (4). Syenite (5). Granite (4). Porphyrite (40). Diorite. Flint.

(*l*) Kaims, Angerton, on the Wansbeck:—

Greywacke. Syenite (2). Granite (5). Porphyrite.

(*m*) Gravels (fluvio-glacial?), Wansbeck, near Mitford:—

Greywacke (7). Syenite (12). Granite (33). Porphyrite (5). Whin (3). Chert. Hornblende schist.

(*n*) Boulder clay, Lough Hill, Sweethope, head of Wansbeck:—

Greywacke. Syenite (8). Granite (9). Andesite (Borrowdale?) (3). Diorite. Mica syenite (2). Chert (2). Quartz porphyrite.

(*o*) Kaims, Liddle Hall, Hallington Reservoir:—

Greywacke (4). Syenite (8). Granite (16). Andesite (Borrowdale?) (2). Jasper. Schist. Gneiss. Chert.

(*p*) Boulder clay, Prestwick Burn, near Redesmouth:—

Granite. Andesite (Borrowdale?).

Glacial Striæ.

The following striations on the rock surface have been reported:—

Locality	Height, in Feet, above Sea-level	Direction	Rock Striated
(*a*) *Observed by* Dr. Smythe.			
1. Benton, railway cutting east of station.	200	S.E.	sandstone
2. Tranwell, ½ mile east of	240	E.	sandstone
3. Lesser Wannies, head of Wansbeck. .	1,000	E. by N.	grit
4. Horsebridge Head, just north of mouth of Wansbeck	10	S.	sandstone
5. Newton Sea Houses	0	S. 35° E. and S.	whin
6. South Charlton, ½ mile W.N.W. of .	500	E. and S. 10° E.	sandstone
7. Fontburn, waterwork just west of station	600	N. by E.	whin
8. Ritton White House Quarries, east of Fontburn	840	E. and S.	whin
(*b*) *Observed by* Dr. Woolacott.			
9. Salterfen rocks, 2 miles south of Sunderland	0	S. 17° E.	magnesian limestone

Reported by the Hull Geological Society.

Mr. C. Thompson, B.Sc., reports that he has obtained from the boulder clays of Holderness, chiefly from the neighbourhood of Aldbrough, ammonites representing *all* the zones of the Yorkshire Lias. In addition recent work has yielded at least twenty species new to Yorkshire records, or only doubtfully inserted therein.

Mr. S. S. Buckman has named nineteen of these specimens, and they include at least four species new to science.

The excavations for the new dock at Marfleet, near Hull, have disclosed some fine sections in the Humber warps, forest beds, and underlying glacial clays. From the latter, two boulders of shap granite have been obtained, the larger of which measures 16 × 14 × 12 inches.

Mr. Stather reports that, as a result of the work done by Dr. V. Milthers on the Scandinavian boulders found in Denmark, and the examination of type rocks with which Dr. Milthers supplied him, he has been able to recognise several types not previously recorded from the Yorkshire boulder clays.

Dr. Milthers recognises many Scandinavian erratics in Denmark, and divides them into five classes:—

(1) Those from Christiania district.
(2) Those from Dalarne district.
(3) Those from Scania.
(4) Those from Eastern Småland.
(5) Those from the North Baltic, Åland, &c.

It is, of course, well known that rocks from the Christiania district are of common occurrence in the drifts of our East Coast, and with Mr. Milthers' specimens for reference three new records have already been made, and it is hoped that it will be found possible to identify many of the other rocks.

The new records are—

(1) Bredvad porphyry from Dalarne.
(2) Gronklitt porphyrite from Dalarne.
(3) Red Särna porphyry from Dalarne.

Mr. Stather expresses the opinion that the Dalarne rocks will be found to be quite as common in the glacial beds of the East Coast as are those from the Christiania district.

IRELAND.

Reported by the Committee of the Geological Section of the Belfast Naturalists' Field Club.

The Committee record the extension of Ailsa Craig Riebeckite-eurite to Coleraine (see below).

Co. Armagh.

Armagh (*cutting through boulder clay*, Light Railway, near Armagh).—230 boulders noted; 64 per cent. were erratics, and included

60 basalt, 22 sandstone, 18 schist, 12 quartz, 10 porphyry, 6 granitic rock, 1 jasper, 1 syenite, 3 Permian, 1 lignite, 9 chalk and flint, 2 grit, 1 felsite, 1 gneiss, 1 quartzite. The subjacent rock is Carboniferous limestone. The prevailing directions of the parent rocks are N. or N.E.; two are N.W.

Foraminifera found in the clay.

Armagh (Esker S.W. of Carrick-a-loughran Quarry).—100 pebbles noted, 35 per cent. were erratics, and included 24 basalt, 6 mica schist, 4 quartzite, 1 flint. A fragment of Balanus was also found. The clayey sands yielded foraminifera.

Ailsa Craig Riebeckite-eurite, petrified wood from Lough Neagh, and foliated gneiss have also been recorded from the Armagh Drift.

Co. Tyrone.

Cookstown (Quarry and railway cutting).—About 240 feet above sea-level. Subjacent rock, Carboniferous limestone. 112 boulders noted, 25 per cent. erratics, comprising 8 basalt and dolerite, 1 granite, 3 felstone, 1 aphanite, 11 quartz, 2 quartzite, 1 schist, 2 grit. Prevailing direction of parent rocks N. or N.E.; one granite, probably from S.W. Foraminifera found in the clay.

Co. Down.

Annadale and Messrs. Martin's Brickyards (on right bank of Lagan). Cliffs about 40 feet high of stiff stratified reddish-brown boulder clay. Subjacent rock is Trias. Erratics noted—a large number of basalt and chalk, also 9 Ailsa Craig Riebeckite-eurite, 2 rhyolite (Templepatrick), 3 eurite (Tornamoney), 3 schist, 3 gneiss, 1 gabbro, 1 Carboniferous limestone, 2 greensand, 2 chert, 1 granite, 1 Silurian shale, 1 White Lias (Larne), 2 Carboniferous sandstone (Ballycastle), 3 Lias, 1 Felsite, 4 Magnesian limestone.

Cretaceous and Lias fossils were noted. The sand intercalated in the boulder clay yielded foraminifera.

Co. Antrim.

Lisburn.—Esker; subjacent rock Trias. Erratics comprised basalt, granite, porphyry, porphyrite, clay ironstone, grit, conglomerate, quartzite. Prevalent direction of parent rocks N. and N.E.; one from N.W.

Ballymena District.—Eskers at Drumfane and Broughshane. Subjacent rock, basalt. Boulders at both places mostly of local origin. Out of 100 noted at Drumfane, 70 were basalt, 21 rhyolite, 4 chalk, 2 flint, 2 dolerite, and 1 Cushendall porphyry. Out of 100 noted at Broughshane, 76 were basalt, 4 flint, and 20 chalk.

Co. Londonderry.

Coleraine: Carthall Brickworks.—Boulder clay and sand at one pit in vertical bands. Subjacent rock, basalt, very few boulders, these included erratics of chalk, flint, slate, and porphyry. The sand was examined and yielded foraminifera.

Coleraine: Spittle Hill Quarry.—Subjacent rock basalt. Reddish boulder clay, varying in height from a few up to 20 feet. 100 boulders noted, 42 per cent. were erratics, comprising 1 Ailsa Craig Riebeckite-eurite, 24 flint, 6 quartzite, 3 granite, 2 eurite, 4 bole, 1 quartz, 1 bauxite.

Portstewart: Sandhills.—Erratics noted—Ailsa Craig Riebeckite-eurite, granite (probably from Barnesmore Gap, Co. Donegal), porphyry from Cushendun, eurite from Tornamoney Point, quartzite from Cushendun area, gneiss, chalk, flint, schist, chert, also granite, probably from Clyde area.

Mr. Robert Bell reports having found a Carboniferous coral, *Lithostrotion Portlocki*, in boulder clay, overlain with about seven feet of peat, at Sluggan Bog, Drumsough, Co. Antrim.

Faunal Succession in the Lower Carboniferous Limestone (Avonian) of the British Isles.—Report of the Committee, consisting of Professor J. W. Gregory *(Chairman)*, Dr. A. Vaughan *(Secretary)*, Dr. Wheelton Hind, *and* Professor W. W. Watts, *appointed to enable* Dr. A. Vaughan *to continue his Researches thereon. (Drawn up by the Secretary.)*

Lower Carboniferous Zones.—Faunal Correlation of the Dinantian of Belgium with the Avonian of Britain.

I was able, in the summer of 1909, to study the most important sequences in the Lower Carboniferous of Belgium; the subjoined correlation is the result of observations then made.

My thanks are most gratefully tendered to those who so ungrudgingly devoted their time to my assistance; to Mr. G. Delépine, of the Catholic University of Lille, who planned the itinerary and accompanied me throughout my visit; to Mr. A. Carpentier, of the same University, who conducted me over the Avesnes district of N.E. France; to Dr. F. Kaisin, of the University of Louvain, for his guidance in the Dinant district; to Mr. P. Destinez, of the University of Liège, for help at Visé and in the study of his collection; to Dom. P. Béda for help at Maredsous and in the abbey collection; and to Prof. H. Dorlodot for the gift of papers and books.

In the matter of stratigraphical terms and indices I have, necessarily, adhered to the official publication, 'Légende de la Carte géologique de la Belgique (1900),' only introducing the notation of Dorlodot for two new terms, *T1d* and *T2c*.

For the most recent and authoritative account of the Belgian rocks and of their stratigraphical relations reference has been made to two mutally supplementary papers by Prof. Dorlodot, entitled 'Les Faunes du Dinantien et leur signification stratigraphique,'[1] and 'Description

[1] *Bull. Soc. belge de Géol.*, t. xxiii. (1909), Mém.

succincte des Assizes du Calcaire carbonifère de la Belgique et de leurs principaux facies lithographiques '[1]; additional details have been taken from an earlier paper by the same author, 'Le Calcaire carbonifère de la Belgique.'[2]

Fossils are employed in the works above cited in two ways, viz.:—

(*a*) In the recognition of levels by the maxima of particular forms or groups (identified by approximate formulæ), *e.g.*, *Spiriferina* '*octoplicata*,' *Productus* '*Cora*.'

This method, employed without check, is subject to large errors of identification and of range: thus *Spiriferina* '*octoplicata*' ranges throughout Z and γ, and may occur at any level within this range should conditions be favourable.

(*b*) In the numerical comparison of a new fauna with the known faunas of Tournai and Visé.

This method (1) takes no account of the identity of genera due to similarity of phase; for example, the Waulsortian facies is for this reason more similar to Visé than to Tournai. (2) It does not weight fossils according to their abundance; and (3) it takes account of persistent gentes which happen to be unrepresented at one of the localities, but are present at the other, *e.g.*, *Pugnax* (*Rhynchonella*) *pugnus* would count as Viséan, although common in the Middle Devonian.

Within the present year two attempts have been made to compare the faunal sequence in Belgium with that of the British Isles, namely: (1) 'Calcaire carbonifère de Belgique: Comparaison au Sud-Ouest de l'Angleterre,' by Mr. G. Delépine,[3] and (2) 'Comparison entre les couches du Calcaire carbonifère de Belgique et celles de l'Angleterre,' by Dr. Paul Gröber, of Strassburg University.[3]

Mr. Delépine bases his partition of the series upon the recognition of fossil 'bands' (or assemblages), each of which characterises a particular level (*under usual conditions*); the range of a species or gens is intentionally neglected.

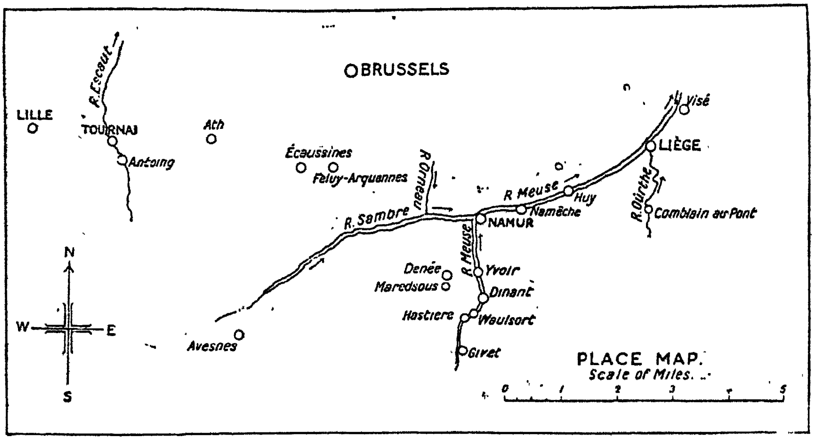
This method, which is essentially that involved in the use of 'marine bands' in the coal measures, leads to highly satisfactory results so long as phasal conditions do not introduce a strange fauna, and so long as no greater accuracy of position is sought than that involved in the large zones now in use. The considerable number of forms necessary for the identification of a band supply the necessary correction of errors of identification, and no greater palæontological aptitude is demanded than is involved in recognising a broadly formulated species. The results set out by Mr. Delépine are in general accord with the subjoined correlation.

Dr. Gröber deals only with the Tournaisian, but is to be applauded for his pioneer attempt to subdivide the C zone by means of variations in the gentes of *Caninia* and *Cyathophyllum*.

It is too early as yet to judge of the value of his results. I am myself engaged upon the same problem in the course of a minute revision of the faunal sequence at Burrington (Mendip), and Mr. A. Salée, of the

[1] *Bull. Soc. belge de Géol.*, t. xxiii. (1909), Mém.
[2] *Ann. Soc. Géol. du Nord*, t. xxiii. (1895), p. 201.
[3] *Bull. Soc. belge de Géol.*, t. xxiv. (1910), Mém.

Geological Institute of Louvain, has just completed an exhaustive examination of *Caninia patula* and *Caninia cylindrica*.



Notes on Localities (see Place Map, above).

I. TOURNAI and ECAUSSINES: Viséan absent.

At Tournai:—

All the quarries are in the Upper Tournaisian and exhibit Z-γ, capped by *Caninia* beds of C_1 age (*i.e.*, beds containing *Can. cylindrica*, accompanied by *Can. patula* and *Can. cornucopiæ*). The change of phase above Z-γ probably took place at slightly different times at different points, *e.g.*, at Allain and Vaulx, but as yet the knowledge of ranges is not sufficient to detect the variation.

Near Ath and Écaussines:—

The base of the Carboniferous rests upon the transition beds (considered to be uppermost Devonian), and contains the characteristic β-fauna.

The Upper Tournaisian exhibits the same zonal range as at Tournai—namely, Z-γ, capped by *Caninia*-beds of C_1.

II. NAMUR BASIN (Valley of Sambre and Meuse): the Orneau, Namur, Huy.

Ascending sequence.

Transition beds followed by β.

Dolomitisation obscures the sequence up to S_1; certain levels, however, such as γ-C_1, and C_2 with *Prod. sublævis*, have been carefully followed by Mr. Delépine.

S_1, both faunally and lithologically, is practically identical with the same level in the Bristol area.

In S_2, *Lithostrotion* enters later than in Britain.

The 'pseudo-breccia' with *Prod. undiferus* occurs at the top of S_2, and is apparently a little earlier than the true 'Grande Brèche' of the Dinantian.

Correlation *of* Avonian *and* Dinantian.

Avonian Zones		Dinantian Divisions (Légende de la Carte géol. de la Belgique)		Assises		*Stratigraphical Record of Belgian Succession.* Limestones and Shales	'Récifs' and Similar Accumulations ('Knoll' Phases)	Deposits at Sea-level	Fauna	
Upper Avonian	Dy	Viséen	V2c	Visé	*Prod. giganteus* (Mart.), de Kon.	Calcaire noir à *Prod. longispinus*	'Brachiopod Beds of Visé'	Plant Beds	Dy	At Visé:— *Lonsdalia conaxis* (M'Coy); *Cyclophylla*; *Dibunophylla*; *Lithostrotion junceum* (Flem.), Ed. and H.; *Prod. striatus* Fischer, de Kon.; *Prod. latissimus* Sow. and the Brachiopod fauna of Wetton, &c.
	D2					Calcaire à *Prod. giganteus*			D2	Elsewhere:— *Prod. longispinus*, var. *setosus* Phill.; *Prod. giganteus* (Mart.); *Spirifer striatus* (Mart.); *Campophyllum* nr. *murchisoni* Ed. and H.
	D1		(V2c)x					Grande Brèche		
	'Concretionary Beds'						Calcaire à *Prod. undiferus*		S–D	*Prod. undiferus* de Kon.; *Seminula ficoides* Vaughan; *Lithostrotion irregulare* (Phill.), Ed. and H.
	S2		V2b		*Prod. cora* d'Orb de Kon.	Calcaire à *Lithostrotion*		'petite brèche' (='brecoidal pisolite') (affecting beds within these limits)	S2	*Seminula ficoides* Vaughan; *Prod. corrugato-hemisphericus* Vaughan (=*Prod.* '*Cora*'); *Lithostrotion martini* Ed. and H.; *Carcinophyllum θ* Vaughan
	S1		V2a			Calcaire à *Prod.* '*cora*' Marbre noir de Denée (and 1st level of '*Prod. giganteus*')			S1	*Caninia bristolensis* Vaughan; *Prod. θ* Vaughan (=*Prod.* '*giganteus*'); *Prod. semireticulatus*, mut. S1 Vaughan
	'Bellerophon Beds' C2		V1a	Dinant	*Chonetes papilionacea* Phill., de Kon.	Calcaire à *Prod. sublævis* | 'Grande dolomie' à *Chonetes* cf. *comoides* Marbre noir de Dinant	(Sosoye)	Plant Beds	C2	*Cyathophyllum φ* Vaughan; *Michelinia grandis* M'Coy; *Syringopora favositoides* Vaughan M.S.; *Prod. sublævis* de Kon. and var. *Prod. christiani* de Kon.
Mid-Avonian Line							(Waulsort) 'Waulsortien' (affecting beds within these limits and containing 'Brachiopod Beds' at the levels indicated)	Brèche de Comblain-au-Pont		
Lower Avonian	C1 γ	Tournaisien	T2c (Dorlodot) T2b T2a	Écaussines et Waulsort	*Sp. konincki* Dew. (=*Sp. cinctus* de Kon.)	Calcaire de Paire et de Vaulx (= *Caninia* Limestones of the Ourthe and of Tournai) (Écaussines) (Ourthe) (Maredsous) 'Petit Granit' (affecting beds within these limits and extending up to the different levels indicated) Calcaire d'Yvoir	(Maredsous)	'*laminosa*-dolomites'	C–S	Waulsortian:— *Spir. princeps* M'Coy; *Sp. suavis* de Kon.; *Sp. pinguis* Sow.; *Prod. plicatilis* Sow. and *Prod. mesolobus* Phill.; *Prod. fimbriatus* Sow.; *Prod. youngianus* Dav. *Pugnax pugnus* (Mart.); *Pugnax plicata* (Sow.); *Dielasma hastata* (Sow.) *Amplexus coralloides* Sow. is the only coral
									C1	Max. of *Caninia cylindrica* (Scouler); *Chonetes* cf. *Comoides* (Sow.); (*Orthotetes*) *strophomenoides* Vaughan
									γ	Petit Granit:— *Caninia cylindrica* (Scouler); *C. patula* Mich.; *C. cornucopiæ* Mich. *Cyath. θ* Vaughan and Canino-cyathophyllids; *Spir. konincki* Dew.; *Prod. burlingtonensis* Hall; *Prod. pustuloides* n.sp.
	Z2		T1d (Dorlodot)	Hastière	*Spirifer tornacensis* de Kon.	Calschistes de Maredsous (and of Feluy)			Z	Typical Z assemblage of Brachiopods and small *Zaphrentes*; a max. of *Spir. clathratus* M'Coy (=*Spir. tornacensis* de Kon.) *Caninia gigantea* (Le Sueur), (Ed. and H.); *Syringothyris carteri* Hall, Schuchert; *Prod.* aff. *bassus* Vaughan
	Z1		T1c			Calcaire de Landelies		(Maredsous and Comblain) (?)		
	β		T1b			Schistes à *Spiriferina* '*octoplicata*'		(Huy and Ath)	β	*Zaphrentis vaughani* Douglas; Small Caninid; *Spiriferina peracuta* de Kon. (=*Spiriferina* '*octoplicata*')
	K2		T1a			Schistes et Calcaires d'Hastière		(Hastière)		
		Devonian				N.B.—Dolomitisation affects the sequence over variable intervals. The main level is immediately below S, but in the Namur district dolomitisation commences in β and extends into S1		Siliceous rock types (psammites and macignos) extending up to different levels as indicated		N.B.—Only the most important Brachiopods and Corals are cited in the above lists. The naming accords with that of my Bristol and later papers
	K1	Famennian	Fa, 2d	Comblain-au-Pont						
	Old Red Sandstone									

To face p. 108.]

The highest beds, with *Prod. longispinus*, can be assigned to Upper D.

III. THE OURTHE VALLEY (Comblain-au-Pont).

Two types of Tournaisian sequence are exhibited side by side:—

(1) Rivage to Liotte.

The upper part of the transition series apparently contains a Carboniferous fauna.

The shales that succeed certainly contain *Spiriferina*, but the accompanying fauna suggests a level in Z higher than β. [Similar shales underlie 'petit granit' at Maredsous.] These shales are overlain by Z-γ and the *Caninia* beds of C_1.

(2) N. of Comblain-au-Port.

The 'petit granit' of the Ourthe, Z-γ, is succeeded by '*laminosa* dolomites,' C_1, similar, faunally and lithologically, to the beds of the same phase in the Bristol area.

These dolomites are capped by a calcareous conglomerate (Brèche de Comblain-au-Pont), recalling the *megastoma*-conglomerate of County Dublin.

IV. DINANT DISTRICT (Gorge of the Meuse: Hastière, Dinant, Yvoir)—the type sections of the Dinantian.

The correlation table gives the main points in the comparison between the complete sequence of this district and that of the Avon. The following notes may be added:—

'Calcaire d'Yvoir' and 'Petit Granit' (when present) must both be included in Z-γ.

The Calcaire de Leffe of Dorlodot must be correlated with the top of the Tournaisian by relative position only, since it is practically unfossiliferous.

The highest black limestones and shales, discovered by Mr. Delépine between Dinant and Yvior, contain a well-marked Upper D fauna.

V. The WAULSORTIAN. (The District West of Dinant: Hastière, Waulsort, Maredsous, Sosoye.)

The levels suggested for the various Brachiopod beds are deduced from

(*a*) the relative predominance of *Spirifer* and *Productus*. Spirifer predominant indicates Tournaisian, as in the 'récif' of Maredsous.

(*b*) The occurrence of 'Viséan species' of *Productus*, such as *P. margaritaceus*, *e.g.*, at Sosoye.

(*c*) Stages of structural development.

N.B.—Care must be taken to eliminate certain species that are apparently persistent throughout the Lower Carboniferous and that recur at every renewal of similar conditions, *e.g.*, *Pugnax acuminata*, var. *plicata*, and *Pugnax pugnus* among Brachiopods and *Amplexus coralloides* among Corals.

VI. Visé.

The whole of the Carboniferous limestone of Visé belongs to the Upper *Dibunophyllam* zone, for the lowest beds (said to rest unconformably on the Devonian) contain *Dibunophylla* and *Densiphylla* of Upper D habit.

The higher limestones contain species of *Dibunophylla*, *Cyclophylla*, &c., which ally them to the coral beds of Derby and North Wales. In accord with this is the fact that the Brachiopods are identical with those of the Brachiopod beds of Wetton, &c.

Visé is the only locality in Belgium at which a characteristic D coral fauna has been discovered. In N. France, near Avesnes, the uppermost limestones with *Prod. latissimus* contain an identical coral fauna indicating D_2-Dy.

Investigation of the Igneous and Associated Rocks of the Glensaul and Lough Nafooey Areas, Cos. Mayo and Galway.—Report of the Committee, consisting of Professor W. W. Watts (*Chairman*), Professor S. H. Reynolds (*Secretary*), Mr. H. B. Maufe, *and* Mr. C. I. Gardiner.

Mr. C. I. Gardiner and the Secretary completed their field-work on the Glensaul area in April 1909, and their paper was published in the 'Q. Journ. Geol. Soc.,' vol. lxvi. (1910), pp. 253-279. At the same time they commenced work on the rocks of the Kilbride peninsula (Lough Nafooey area), and have devoted three weeks in July and August 1910 to a continuation of the work, which is not yet completed. The general structure, however, of the Kilbride Peninsula may be briefly described as follows. The southern and eastern part consists in the main of Silurian grits and flags, dipping with great regularity in a general south-easterly direction, and including a highly fossiliferous Upper Llandovery horizon. The northern and western portion consists principally of igneous rocks—quartz felsite, vesicular andesitic rocks, labradorite porphyrite, and coarse breccia. As yet the only fossils found in this part of the area are a few Didymograpti and a crustacean, probably a species of Caryocaris. In the south-eastern corner of the peninsula is an area of gneissic rocks against which the Silurians are faulted.

Composition and Origin of the Crystalline Rocks of Anglesey.—Fifth Report of the Committee, consisting of Mr. A. Harker (*Chairman*), Mr. E. Greenly (*Secretary*), Dr. J. Horne, Dr. C. A. Matley, *and* Professor K. J. P. Orton.

The end of the present geological work upon Anglesey is now within sight. The map will, all being well, be completed during the coming autumn, after which the descriptive memoir will be the only undertaking

of importance. While this is proceeding, Mr. J. O. Hughes will devote nearly all his available time to such analyses as are likely to throw light upon the origin of widespread types of rock in which metamorphism has produced such complete reconstruction as to efface all traces of original sedimentary or igneous structures.

Of these rocks two have been attacked during the year now past, with the following results:—

No. 519A.—Great Jasper, Newborough.

	I.	II.
SiO_2	93·51	93·54
Fe_2O_3	6·60	6·52
Alkalies	none	—
	100·11	100·06

This is an unusually large jasper, occurring in a limestone associated with the ellipsoidal diabase lavas.

No. 231A.—Basic Schist, Capel Soar, Bodorgan.

	I.	II.
SiO_2	45·83	46·06
TiO_2	trace	—
Al_2O_3	17·45	17·34
Fe_2O_3	4·64	4·73
FeO	7·52	7·46
MnO	trace	—
CaO	11·14	10·96
MgO	8·37	8·21
K_2O	0·16	0·12
Na_2O	2·88	2·84
H_2O (at 110°)	0·21	0·28
H_2O (above 110°)	2·23	2·20
	100·43	100·20

This is a rock, now completely reconstructed, which is certainly derived from the same lavas in another district.

Besides these the following miscellaneous rocks have been analysed on account of their special interest:—

No. 426A.—Ophicalcite; Holyhead Island.—This is the beautiful 'Mona marble,' associated with the Serpentines and Gabbros:—

	I.	II.
Residues insoluble in HCl	16·35	18·29
Soluble SiO_2	0·60	0·41
$Al_2O_3+Fe_2O_3$	9·17	8·31
CaO	38·88	38·78
MgO	2·44	1·98
CO_2	31·08	31·12
H_2O undetermined	—	—
	98·52	98·89

As the above analyses indicate, digestion with hot HCl is not very suitable in this case. The rock evidently contains silicates which are

decomposed by the acid, and it was found impossible to obtain concordant values, especially for the insoluble portion and for the magnesia. It was therefore decided to try acetic acid instead, since this acid dissolves calcium carbonate but does not readily attack silicates. This method, as the following analyses indicate, was very successful, and is evidently suitable for the analysis of metamorphic limestones containing silicates:—

	I.	II.
Residues insoluble in acetic acid	28·21	28·14
$Al_2O_3+Fe_2O_3$	0·08	0·17
CaO	38·89	39·01
MgO	0·53	0·46
CO_2	31·08	31·12
H_2O	1·08	1·13
	99·87	100·03
Percentage $CaCO_3$	69·44	69·66

θ. Red Limestone; Tyddyn Du, Amlwch.

	I.	II.
Residues insoluble in HCl	14·97	15·13
$Al_2O_3+Fe_2O_3$	4·30	4·24
CaO	27·51	27·60
MgO	14·84	14·82
CO_2	38·05	38·16
	99·67	99·95
Percentage $CaCO_3$	49·12	49·28
„ $MgCO_3$	31·16	31·12

Several masses of peculiar limestone of this type occur in the schists of the northern region.

No. 550A.—Ironstone in Llandeilo shales, Llanbabo. Only the iron has been estimated in this rock; the actual state of combination has not been determined:—

	I.	II.
Total Iron (calculated as Fe_2O_3)	26·94	27·04

This is an ironstone, sometimes very oolitic, which occurs in the *Nemagraptus gracilis* shales, and may be of some importance.

ε. Massive Grey Limestone, in Old Red Series.

	I.	II.
Residues insoluble in HCl	9·11	9·04
$Al_2O_3+Fe_2O_3$	0·88	0·97
CaO	50·15	50·22
MgO	—	—
CO_2	39·59	39·65
	99·73	99·88
Percentage $CaCO_3$	89·55	89·68

ζ. Red Limestone, in the same beds as above.

	I.	II.
Residues insoluble in HCl	15·63	15·72
$Al_2O_3+Fe_2O_3$	2·35	2.39
CaO	41·88	41·93
MgO	3·11	3·03
CO_2	36·69	36·74
	99·66	99·81
Percentage $CaCO_3$	74·78	74·87
„ $MgCO_3$	6·53	6·36

Both the above rocks are from the Penrhoslligwy district.

Dolomite.—From shore east of Porth Penmon.

	I.	II.
Residues insoluble in HCl	0·85	0·89
$Al_2O_3+Fe_2O_3$	2·08	2·02
CaO	30·17	30·03
MgO	20·84	20·86
CO_2	46·48	46·44
	100·42	100·29
Percentage $CaCO_3$	53·87	53·71
„ $MgCO_3$	43·59	43·63

This is a thick, massive bed in the Carboniferous limestone.

Finally, in a peat ash from Cors y Bol, Llantrisant, an extensive old alluvium, the percentage of phosphoric acid has been determined:—

	I.	II.
Percentage P_2O_5	1·71	1·79

And one of the well-known hornblende picrites of Llandyfrydog has been examined for nickel, as there was an impression that this existed in it in some quantity, but no nickel was detected.

Mr. Hughes desires to point out that his leisure for research work during the past session has been rather small, and that the greater part of his analytical work will be done in the coming summer vacation —too late, that is, for the results to appear in this report.

The Excavation of Critical Sections in the Palæozoic Rocks of Wales and the West of England.—Report of the Committee, consisting of Professor C. LAPWORTH (*Chairman*), Mr. G. W. FEARNSIDES (*Secretary*), Dr. J. E. MARR, Professor W. W. WATTS, *and* Mr. G. J. WILLIAMS.

[PLATE III.]

Third Report on Excavations among the Cambrian Rocks of Comley, Shropshire, 1909, by E. S. COBBOLD, *F.G.S.*

THE excavations made during 1907 and 1908 were reported upon to the Dublin and Winnipeg Meetings of the British Association. As the funds placed at my disposal by the Committee appointed in 1907 had not been

fully exhausted, I continued the excavations in the summer of 1909. These excavations form the subject of this third communication, which is final so far as this grant is concerned.

The excavations of 1909 extend beyond the limits of the sketch map originally printed, and necessitate a new one (see Plate III.). On this the positions of all the principal excavations are shown by bold numbers. Where a clear dip has been observed, the exact position is indicated by the point of the arrow, but where the dip is uncertain the position is marked by a black dot. In addition to the lines of all roads, fences, streams, and footpaths, contours have been sketched in at intervals of 20 feet vertical, and a little shading has been added to bring out the relief of the surface. The tracks of some of the principal faults, seen or inferred during the progress of the excavations, are shown by dot-and-dash broken lines, and the general positions of the rocks of various ages bounding the Comley Cambrian area are indicated in words.

With the exception of No. 27, which comes in the central portion of the Comley area, the excavations now to be described were made in two distinct parts of the area—(A) the Shoot Rough side, to the north-east of the quarry; (B) the Robin's Tump portion, to the south.

Excavation No. 27, Francis' Field.

Near a farm south of Dairy Hill and east of Hill House Ridge, there is a small prominence on which the soil indicates that rock is near the surface. An excavation was made on the west slope, and disclosed some 4 or 5 feet of very broken shale, with obscure indications of a northerly strike and a high westerly dip. No fossils were discovered, and further exploration near this point was deferred until other more promising excavations had been disposed of.

A.—The Excavations on the Shoot Rough Side.

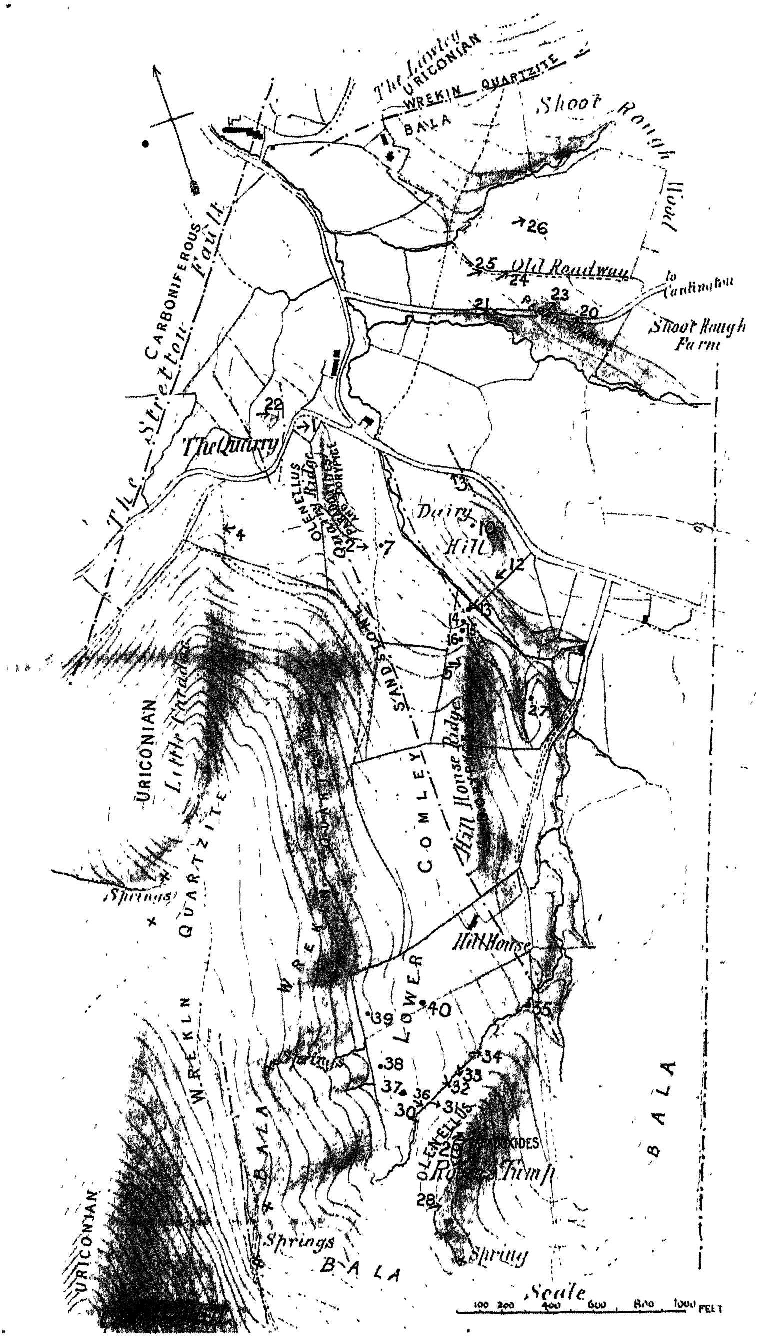
The report to the Winnipeg Meeting gave details of the beds called Shoot Rough Road Shales and Shoot Rough Road Flags at excavations No. 20 and No. 21. Leave having been obtained to make openings in the fields north of the road, these excavations were extended, and additional trials were made with a view to ascertain, if possible, the nature of the rocks between the Shoot Rough Road beds and the supposed Tremadoc of Shoot Rough Wood.

Excavation No. 20, Shoot Rough Road, Upper Section[1] *(Extension of).*

A trench was dug at right angles to the strike from the highest beds of shale previously observed. The shale was followed for a horizontal distance of 13 yards, where its surface sank out of sight under the thickening covering of drift. Allowing for the dip of 45° to the north-east, the thickness of shale seen would be about 40 feet, and in this no fossils were discovered, nor was there any change in the general character of the rock.

[1] *Brit. Assoc. Report*, 1909 (Winnipeg), p. 184.

SKETCH MAP OF THE COMLEY AREA.



Illustrating the Report on the Excavation of Critical Sections in the Palæozoic Rocks of Wales and the West of England.

Excavation No. 23.

The surface feature made by the outcrop of the Shoot Rough Road Flags is traceable in a north-westerly direction for about 100 yards from excavation No. 20. A trench was opened across this feature and continued south-westerly to ascertain, if possible, the nature of the beds underlying the flags. At about 18 feet below the top of the flags a band of rotten stone was touched, yielding residual nodules of calcareous sandstone, and containing plentiful remains of *Paradoxides rugulosus* Corda. At about the horizon of this bed the flags graduate into a soft greenish micaceous sandstone, like that noticed at the east end of excavation No. 21.[1] A thickness of 3 feet of this sandstone, now called the 'Shoot Rough Road Sandstone,' was exposed, but its further downward continuation could not be ascertained, owing to the increasing thickness of detrital matter from the escarpment of the flags above. With the help of my friends, Rev. W. M. D. La Touche and Mr. C. D. Walton, I secured further fossils from the flags of the original section (No. 20); they include a small *Microdiscus* very like *M. punctatus*, form *eucentrus* Linn., but not sufficiently well preserved to identify with certainty, and a form recalling *Ptychoparia* (*Liostracus*) *Linnarssoni* Brögger.

Combining the observations of 1908 and 1909, the complete section across these Shoot Rough Road Flags may be summarised thus:—

a. Shoot Rough Road Shales (top not seen)	40 feet
b.[2] Shoot Rough Road Flags	18 feet
Additional fossils—*Microdiscus*, sp., cf. *M. eucentra* or *M. punctatus* Salter—*Ptychoparia Linnarssoni* Brögger ? and	
c. Shoot Rough Road Sandstone	1 foot
c_1 Calcareous band *Paradoxides rugulosus* Corda, '*Lingulella ferruginea* Salter, *Acrotreta* or *Acrothele*, sp.'[3]	1 foot
c_2 Green Sandstone (base not seen)	3 feet

Excavation No. 21, *Shoot Rough Road, Lower Section.*[4]

In order to examine the nature of the junction of the shales and gritty flags of this lower section a trench was opened parallel to the original exposure, but at a distance of 5 or 6 feet, and on the other side of the hedge, where it was possible to excavate to a depth of about 5 feet without danger. The new section disclosed was as follows:—

West End of the Section.

a. Shales comparable with the Shoot Rough Road Shales of the upper section dipping at a very high angle to the east-north east (top not seen)	9 feet
b. Gritty flags and rotten stone bands—	
b_1. Red earthy rotten stone	5 feet
b_2. Flaggy, sandy bed, dip vertical	3 feet
b_3. Hard greenish bed of grit, dip c^a. 80° north-west	1 foot
b_4. Flaggy beds with shale partings (base not seen)	5 feet

[1] *Brit. Assoc. Report*, 1909 (Winnipeg), p. 185.

[2] Details of these flags are given in the previous report, *op. cit.*, p. 184.

[3] The determinations of the Brachiopods included in inverted commas are those supplied to me by Dr. C. A. Matley.

[4] *Brit. Assoc. Report*, 1909 (Winnipeg), p. 185.

FOSSILS.—

'*Orthis Lindströmi* Linnrs. very plentiful, *Linnarssonia* sp., cf. *L. sagittalis* Salter. *Acrotreta*, sp., *Lingula* or *Lingulella*, sp. indet. but almost certainly not *L. ferruginea* Salter.'

East End of the Section.

The reversal of the dip with complete conformity of the beds is established, and the similarity of their lithological characters with those of the beds of the upper section is so close that very little doubt remains that the two exposures are on the same horizon. The fossil evidence is substantially in agreement, but differs in the more plentiful remains of *Orthis Lindströmi* which is only sparingly represented in the band b_4 of the upper section[1] and the paucity of specimens of *Acrotreta* which is so plentiful in the same band.

Excavations Nos. 24 and 25.

Roughly parallel with the Shoot Rough Road, and to the north of it, there is a line of fence bounding a disused cart-track, which has in places been worn down through the superficial covering to the shaley rock below. Advantage was taken of this to open up the shale in two places. The characters of the shales agree with those of the shales in the road: there are hard siliceous bands in them, half an inch or more in thickness, and also rotten stone bands, usually rather thicker. The strike of the beds is nearly north by west and south by east, and the dip is fairly constant at about 45° to the eastward. A rotten stone band at the spot marked 25 yielded casts of 'a small *Orthis* of the *O. lenticularis* Wahl type. These are not so well preserved as those recorded from beds *a* of the Shoot Rough Road, Lower Section,[2] but are distinctly larger, and seem, so far as their characters are shown, to be closer to the type.' At the southern end of this excavation some harder shale was encountered, characterised by rusty spots, more or less polygonal in shape, and with a radiating crystalline structure extending out from them. At first sight these spots suggested crinoid stems, but they are more probably due to some mineral matter (? selenite).

Excavation No. 26.

Small trials were made at intervals on the surface of the field to the north of the old cart-track in a direct line to the north-east. With one exception these failed to reach solid rock. At the spot marked 26, where there is a slightly steeper rise in the surface, shale was found immediately below the soil, and, on following it in either direction, a continuous section of about 50 feet in aggregate thickness was exposed. The dip and strike remained constant throughout, and sensibly parallel with that of the shales in excavations Nos. 24 and 25. The shale was for the most part fairly hard, with clearly marked laminations, and at either end graduated into softer shale which disappeared below the superficial accumulations. In one part a few more or less polygonal rusty spots similar to those of excavation No. 25 were observed, but, with the exception of an indeterminable fragment of a trilobite and one

[1] *Brit. Assoc. Report*, 1909 (Winnipeg), p. 184. [2] *Ibid.*, p. 185.

'badly preserved brachiopod which suggests *Orthis lenticularis*,' no fossils were discovered.

The total thickness of the Shoot Rough Road shales cannot be safely estimated, owing to want of artificial exposures between the excavations described, but the mapping of the surface indicates a very considerable thickness, amounting to some 300 to 500 feet, or possibly more, for the whole group.

B.—THE EXCAVATIONS NEAR ROBIN'S TUMP.

Robin's Tump, viewed from the north, is a small conical hill about half a mile to the south of the Comley Quarry. It is in the line of, and has the appearance of being a continuation of, the Hill House Ridge, but, geologically, it is very different, and the two features are severed by a somewhat flat area occupied by two fields. The summit rises to about 990 feet and is oval-shaped, with a length of about 20 yards in a north-east and south-west direction. It is connected with the higher (Ordovician) ground at the foot of Caradoc Hill by a saddle some 40 or 50 feet lower in elevation. Several natural exposures of grits and sandstones are to be seen on the summit, but no details of the succession were visible without excavation. A little stream descending from the lower slopes of Caradoc Hill has cut a deep trench along the north-west side, and here there are isolated natural exposures of rather soft greenish and reddish micaceous sandstone of the type of the Lower Comley sandstone, and characterised by burrows and tracks of organisms.

Excavation No. 28, on the Saddle.

Near the place marked 28, trials were made on the Saddle at four spots, all of which showed green micaceous sandstone with a fairly regular north and south strike and a dip to the east of about 45°. The sandstones vary in hardness from point to point, but are otherwise uniform in character, and are evidently part of the series exposed near the stream.

Excavations No. 29, summit of Robin's Tump.

A series of excavations were made in connection with the natural exposures of the summit. These are too close together to be shown separately on the map.

No. 29*a*, situated on the northern shoulder where there was a small natural exposure of much weathered rock, shows about 4 feet of well-bedded coarse calcareous and conglomeratic grit, with many ferruginous casts of fragments of trilobites and grains of bright green glauconite, exactly recalling the conglomeratic portion of the Quarry Ridge grits. The dip is about 45° to a little south of east. Below this conglomeratic bed some 3 or 4 feet of a strong, green, micaceous sandstone are visible, the beds of which dip at a rather steeper angle decidedly north of east. From the solid rock immediately touching the overlying conglomeratic grit I obtained two specimens of cavities, penetrating the sandstone in a curvilinear manner. They are somewhat quadrangular in section, 15 × 20 mm. in diameter, have well-defined

boundaries, and contain cores of coarse gritty material, which come out cleanly, and in substance match with the matrix of the overlying conglomeratic grit. The actual terminations of the cavities were not found. The appearances lead to the conclusion that the sandstone had been bored after the consolidation of the Lower Comley sandstone by some organism capable of removing the cementing material by solution, and of expelling the quartz and other grains thus loosened. Except in the matter of length and shape, the cavities present some analogy to the modern *Pholas* borings in the consolidated Triassic sandstones of the south Devonshire coast. That they were formed after consolidation is rendered the more probable from the fact that the overlying conglomerate, both here and at the Comley Quarry, contains subangular and angular fragments of similar compact greenish sandstone.

No. 29*b*.—In order to confirm the evidence of unconformity exhibited in the last-mentioned excavation, a hole was made on the opposite or south-east side of the summit, where clearly bedded coarse grit of normal Quarry Ridge grit type, with the same dip of 45° to a little south of east, was disclosed.

No. 29*c*.—As No. 29*b* did not show the underlying rock, another excavation was made a few yards away. In this similar grit having the same dip was exposed, but more incoherent and of an ochreous colour, and, underlying it, a breccia of angular fragments of greenish sandstone, separated more or less from one another by coarse, gritty material. Underneath this, again, and partly protruding into it from below, was a rib of solid green sandstone containing a calcareous band, the dip of which was clearly north of east and at a higher angle than that of the grit above it. The divergence between the strikes of the two kinds of rock, both here and in excavation No. 29*a*, is about 30°. The calcareous band contained several specimens of minute *Ostracoda* with a thin chitinous shell and a shagreened surface.

No. 29*d*.—On the north-western side of the summit, and about 25 yards to the south-west of No. 29*a*, some large blocks of rock protruded from the surface, which I refer to the conglomeratic grit, but they are not truly *in situ*. On removing two of these, green sandstone, containing a dark, calcareous band, was found, and some pinkish limestone nodules close to it yielded a profuse number of fossil fragments. Among these there are *Olenellus*, sp., apparently identical with *O. Callavei* Lapw., *Ptychoparia ? annio* Cobbold, *Ptychoparia ? attleborensis* S. & F., *Microdiscus helena* Walc. ?, *Micmacca ?* possibly *M. ? ellipsocephaloides* Cobbold, a fragment of a rather large trilobite not referable to *Olenellus Callavei*, but possibly belonging to the same genus, *Kutorgina cingulata* Bill., *Linnarssonia*, sp. (the same species that is so abundant in the Comley Quarry), *Acrothele* ?, and some small *Ostracoda*.

This fauna, so far as the very fragmentary material has been worked out, is almost exactly the same as that of the Olenellus horizon of the Quarry Ridge, but it does not necessarily follow that it is the same band, and it is not certain whether the nodules are *in situ*, or whether they are pebbles collected in a hollow behind the dark calcareous band. The evidence points to the conclusion that the greenish micaceous sandstone of Robin's Tump belongs to the Lower Comley sandstone as previously

defined,[1] and that it is overlain unconformably by the conglomeratic Quarry Ridge grits of *Paradoxides* age. Further excavations between those numbered 29*a* and 29*d* are urgently required.

Excavations Nos. 30 *and* 35, *at the foot of the North-West Slope of Robin's Tump.*

No. 30.—A natural exposure of Lower Comley sandstone close to the stream was opened out and followed along the strike for about 15 yards. The rock consists of some 6 or 8 feet of greenish micaceous sandstone, dipping at 45° to 50° to the east-south-east, and having numerous cross fractures at right angles to the strike. About midway in the sandstone was a band of clayey material, which on being worked yielded residual nodules of rottenstone and sandy, foraminiferal (?) limestone containing many specimens of a *Hyolithus* approaching to the form *H. fistula* Holl. From this band one external cast of a head shield of an *Olenellus* (apparently an undescribed species) and a few other trilobitic fragments were collected. The band could only be followed for 3 or 4 feet along the strike, and appeared to thin out in the direction of the dip. Both it and the sandstone contain numerous examples of two forms of burrows. Those of form A are subquadrangular in section, with diameters of from 8 to 12 mm. that remain sensibly the same in the short lengths of the specimens collected, and have clearly defined, brown-stained surfaces. Those of form B are much smaller sinuous cavities, without clearly defined boundaries, generally filled with carbonate, but near the surface, with brown earthy matter or roots of plants; they have diameters of about 2 mm.

No. 31.—*About* 30 *yards to the north-east of No.* 30.—A second natural exposure of similar rock was opened out and elongated up the steep slope of the hill so as to cross the bedding at right angles. About 23 feet of beds of greenish micaceous sandstone, varying a little in toughness and becoming reddish purple at the top, were thus exposed, and the dip was observed to remain steadily at 45° to 50° to the south-east.

No. 32.—*About* 45 *yards further towards the north-east.*—A small natural exposure was cleared of soil and vegetation, and proved to consist of reddish purple micaceous sandstone of the same aspect as that at the top of No. 31. The dip, however, has in the interval worked round from south-east to nearly south.

No. 33.—10 *yards further to the north-east.*—Similar rock but of the usual greenish colour was seen here and the dip found to be about 5° to a little west of south.

No. 34.—60 *yards distant from the last to the north-east.*—Similar greenish rock, but rather softer, was seen, and the dip has reverted to the more normal one of about 45° to the east-south-east.

No. 35.—*In the extreme north-east corner of the fences bounding the Robin's Tump area.*—Very fragmentary greenish sandstone was observed at this point, and on opening it out there were obscure indications of a south-easterly dip.

[1] *Brit. Assoc. Report*, 1908 (Dublin), p. 235, *et seq.*

These excavations (Nos. 30 to 35) serve to show that the Lower Comley sandstone occupies the north-western slope of Robin's Tump; that the beds have a general easterly dip, but that this does not remain constant throughout; and further that, in addition to the calcareous bands at the top, the group contains at least one fossiliferous band. From a section plotted to a natural scale along a line up the north-west slope, it appears that this fossiliferous band is approximately 150 feet below the top of the sandstone of the summit, but it is impossible to say whether this estimate of thickness is vitiated by faulting or repetition of beds.

Excavations 36 to 40, in the comparatively flat area immediately north of Robin's Tump.

Openings were made at the places marked in order to ascertain, if possible, the cause of the complete change of surface characters exhibited in passing from the steep and dry slopes of Robin's Tump to the flatter and rather wet space to the north of it, but with no very definite result.

No. 36, in the northern bank of the stream, showed soft greenish sandstone, with a dip parallel to that of No. 30.

No. 37, though pushed down to a depth of 5 feet, produced nothing but broken sandstone of the same type.

No. 38 was sunk to a depth of 4 feet, and yielded clayey material, with a few pieces of the sandstone.

No. 39 was deepened to 5 feet in a dry soil containing many fragments of the same kind of rock.

No. 40 produced nothing but surface clay.

These excavations, coupled with the surface features and the existence of springs in the ground to the west and south-west, suggest the occurrence of a set of thin bedded sandstones and shales below the more compact sandstones of Robin's Tump.

GENERAL SUMMARY OF THE EXCAVATIONS OF 1907-08-09.

The funds originally supplied by the Committee appointed at the Leicester Meeting being now exhausted, it seems advisable to gather together the principal results of the excavations in one statement:—

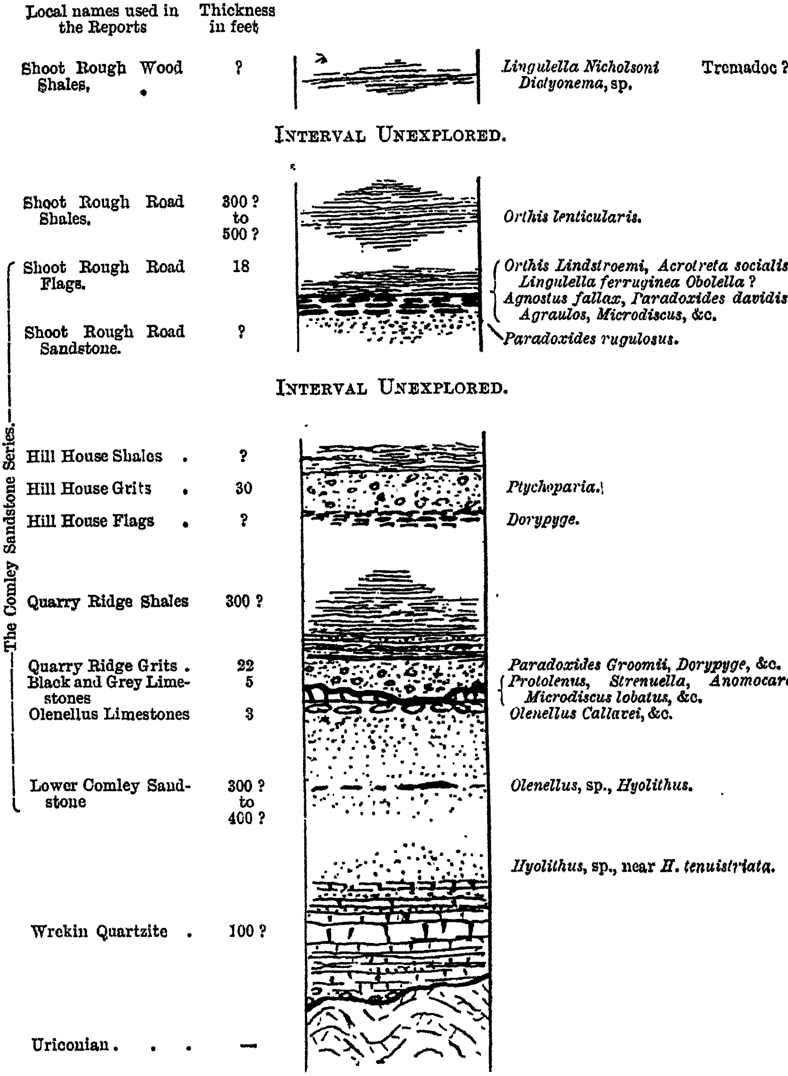
1. The line between the *Paradoxides*-bearing Quarry Ridge grits and the *Olenellus*-bearing Lower Comley sandstone is proved to be marked by an unconformity.

2. Below this line the Lower Comley sandstone has been opened up at several places, and has been proved to contain fossiliferous bands at various distinct horizons. The thickness of the whole group appears to reach to several hundreds of feet, and its lower members pass by gradations into the Wrekin quartzite.

3. The Wrekin quartzite has been opened at two places, and is found to consist of beds of quartzite of very varying thicknesses, with shaley partings.

4. Just above the (previously known) horizon of *Olenellus* (*Holmia*)

Vertical Section of the Cambrian Strata of Comley, Shropshire, from observations made during the Excavations of 1907, 1908, 1909.



Callavei Lapw. and below the unconformity at the base of the *Paradoxides* beds there are some bands of grey limestone, the upper member of which has yielded species of the genus *Protolenus* accompanied by other trilobites, some of which are members of the *Olenellus* fauna in America.

5. The Black Limestone of Comley Quarry occurs above the band

with *Protolenus* and below the base of the Quarry Ridge grits. It has lithological affinities with the Grey Limestones below, and with the grits above, but its faunal affinities are not yet determined.

6. The conglomeratic portion at the base of the Quarry Ridge grits contains angular and subangular fragments of the sandstones and limestones that occur below it, and its matrix yields species of the genera *Paradoxides*, *Dorypyge*, *Conocoryphe*, *Hyolithus*, and *Stenotheca*.

7. The Quarry Ridge grits are succeeded above by a group of shales (interspersed with bands of grit), called the Quarry Ridge shales, and have a thickness of, probably, 300 feet.

8. These shales are followed by the Hill House group, consisting of flags (with *Dorypyge*), grits (with *Ptychoparia* and other undetermined trilobites), and shales of unknown thickness with included bands of grit.

9. A considerable width of unexplored ground intervenes, after which the Shoot Rough Road sandstones—with *Paradoxides rugulosus* Corda and the Shoot Rough Road flags, with *P. davidis* Salter, *Agnostus fallax* Linnrs., *Acrotreta socialis* von Seebach, *Orthis Lindstroemi* Linnrs., and other fossils—have been opened up.

10. Superior to these flags, and in apparent conformity with them, there occurs a large group of shales from which only a scanty fauna has been collected. The dominant species is a form closely allied to *Orthis lenticularis* Wahl.

Owing to the faulted nature of the ground, it is impossible to give reliable estimates of the thicknesses of the various group recognisable in the Comley area. A study of their general disposition and horizontal extent points to an aggregate thickness for the whole of the Comley Cambrians exceeding 1,500 feet, and, very possibly, extending to twice that amount.

The diagram above shows the general relations of the various groups so far as they are at present known. The Shoot Rough Wood shales at the top have not been touched by the excavations. Their Tremadoc age is inferred from Dr. Callaway's discovery in the shales east of the Lawley of '*Lingulella Nicholsoni* and Shineton graptolites '[1] and from Mr. Gibson's subsequent detection in the shales of Shoot Rough Wood of an example of *Dictyonema*.

The thickness (100 feet) assigned to the Wrekin quartzite is taken from Dr. Callaway's estimate,[2] the excavations not having been sufficiently extended to allow of any direct measurement of it being made.

I have again to acknowledge my indebtedness to Mr. Philip Lake for his help in determining the trilobites, and to Dr. C. A. Matley for exhaustively examining the brachiopods of the higher horizons, and I am very grateful to them for their help. My best thanks are also due to Professor Lapworth for continued advice and encouragement during the whole of the excavations.

[1] *Q.J.G.S.*, vol. xxxiv., 1878, p. 758. [2] *Ibid.*, p. 759.

South African Strata.—Report of the Committee, consisting of Professor J. W. GREGORY (*Chairman*), Professor A. YOUNG (*Secretary*), Mr. W. ANDERSON, Professor R. BROOM, Dr. G. S. CORSTORPHINE, Dr. WALCOT GIBSON, Dr. F. H. HATCH, Sir T. H. HOLLAND, Mr. H. KYNASTON, Mr. F. P. MENNELL, Dr. MOLENGRAAFF, Mr. A. J. C. MOLYNEUX, Dr. A. W. ROGERS, Professor E. H. L. SCHWARZ, *and* Professor R. B. YOUNG, *appointed to investigate and report on the Correlation and Age of South African Strata and on the Question of a Uniform Stratigraphical Nomenclature.* (*Drawn up by the Chairman.*)

THE unity in structure and geological history of Africa south of the Zambesi renders it especially desirable that the rocks of the whole subcontinent should be named on a uniform system. The separation of the country into six distinct political divisions—Cape Colony, the Transvaal, Orangia, Natal, Rhodesia, and German South-West Africa—has led to the study of its geology from various centres and to the growth of overlapping systems of nomenclature which are confusing to students in other countries and may give rise to future difficulty in South Africa.

The desirability of uniform names for the chief divisions of South African geology was especially felt during the visit of the British Association to South Africa in 1905. This feeling led to the appointment during the meeting at Johannesburg of a Committee to consider the possibility of securing greater uniformity in practice between the different States. The Committee appointed consists of the following members:—

Representing Cape Colony.—Dr. A. W. Rogers, Professor R. Broom, Professor E. H. L. Schwarz, Professor A. Young (*Secretary*).

Representing the Transvaal.—Dr. G. S. Corstorphine, Mr. H. Kynaston, Dr. F. H. Hatch, Professor R. B. Young.

Representing Natal.—Mr. William Anderson.

Representing Rhodesia.[1]—Mr. A. J. C. Molyneux

Sir T. H. Holland, Dr. G. A. F. Molengraaff, Dr. W. Gibson, Professor J. W. Gregory (*Chairman*).

Owing to the wide distribution of the members, it has not been possible to arrange a full meeting of the Committee, and most of the work has been by correspondence. At meetings of members who could attend in London it was resolved (1) that the object of the report should be to propose a classification and nomenclature that

[1] Mr. F. P. Mennell was added at the Leicester Meeting in August 1907.

could be recommended for adoption among the colonies of South Africa; (2) that the method of procedure should be:—

(a) Preliminary conferences between the members of the Committee resident in each colony, in order that they may report as to the nomenclature and classification best suited to their colony;

(b) The circulation of these reports for consideration by all the members of the Committee;

(c) The submission of all the points at issue in such a form that each member of the Committee can vote upon them by post; and

(d) The preparation of a report stating the opinions of the Committee as thus expressed, and, if possible, to recommend a scheme of correlation and a terminology for adoption by all the South African colonies.

After receipt of the various preliminary reports a series of questions was drawn up by the Chairman and submitted to the members of the Committee for a postal vote.

The results of this vote are tabulated in Appendix I.

I. The Nomenclature of the pre-Devonian Rocks.

The Major Subdivisions.

The first urgent problem concerns the nomenclature and classification of the pre-Devonian rocks.

Some of the South African members of the Committee, especially those for Cape Colony, regard the treatment of this subject as premature. But if no attempt be made to deal with it, there will inevitably develop a varied nomenclature which will be confusing to geologists in other countries when referring to South African work, and may lead in South Africa to the permanent adoption of rival names.

The oldest known fossiliferous rocks in South Africa are the Devonian rocks known as the Cape System. Below this system is a vast series of rocks which are unfossiliferous. The only evidence as to their age is lithological and stratigraphical.

These rocks—excluding the unaltered igneous rocks—include:—

(a) A great series of unfossiliferous sedimentary rocks, quartzites, conglomerates, 'shales,' and sericitic schists;

(b) A series of foliated rocks, including mica schists, hornblende schists, and gneisses; the rocks are partly of igneous and partly of sedimentary origin.

1. The rocks of the Rand are the most important members of the sedimentary group, and opinion is practically unanimous that the rocks of the Rand be called the Witwatersrand System.

2. There is a majority of nine to six in favour of calling the second group—the highly crystalline schists earlier than the Witwatersrand System and occurring, for example, in Swaziland and at Barberton—the Swaziland System, and for adopting that name for the basal crystalline schists of all South Africa. This term is favoured by all the representatives of the Transvaal and Natal, by Dr. Molengraaff

and Dr. Walcot Gibson; but it is rejected by three of the four representatives of Cape Colony, while the fourth (Professor Schwarz) would prefer the adoption of the name Barberton System. The term Swaziland System is also rejected by Mr. Molyneux and Mr. Mennell, the representatives of Rhodesia. The representatives of each State are thus unanimous in their decision for or against the name Swaziland System; and as two States are for it and two against, there does not seem at present any chance of agreement.

There is also no agreement on the Committee as to the name to be adopted for the group to which these two systems probably belong. It depends to some extent on the question of their age.

The sedimentary series, including the quartzites and conglomerates of the Rand, were at one time believed to be Devonian; but they have been gradually moved back to older and older horizons. At present they are regarded as possibly Lower Palæozoic (*i.e.*, Silurian, Ordovician, or Cambrian), but more properly as pre-Cambrian. There is no absolute evidence as to the age of either of the two great pre-Devonian series. It will probably be generally admitted that the non-foliated rocks are younger than the schists and gneisses. It is accordingly tempting to compare the upper series of non-schistose sediments with the Torridonian and Keweenawan, and the lower series to the crystalline schists which usually underlie the pre-Cambrian non-schistose sediments.

This view is, however, based only on lithological evidence. Some members of the Committee are prepared to accept the view that there is such a strong probability of widespread areas of such schists as those of the Swaziland group being pre-Cambrian in age that, until definite evidence to the contrary is forthcoming, they should be accepted as Archean. Such a decision would be convenient, as it would enable the rocks to be given a definite position in the colour scheme used on the maps; and, in the opinion of some members of the Committee, this position is not likely to be altered.

The terms available for these rocks are variously used, so it may be convenient briefly to refer to their history and the present tendency as to their use.

If the Witwatersrand System and older schists be admitted as pre-Cambrian, the first name for them to be considered is that of Archean. This term was first proposed by J. D. Dana in 1872 in a paper on the Green Mountain Quartzite. He there proposes to rule out the older term Azoic, as the era in question was not throughout destitute of life. 'I propose to use for the Azoic era and its rocks the general term Archæan (or Archean), from the Greek ἀρχαιος pertaining to the beginning.'[1] In a footnote he objected to the term Eozoic, owing to the doubtful nature of Eozoum, and explains, 'Whatever part of the Archean beds are proved to belong to an era in which there was life will be appropriately styled the Archeozoic. This term avoids the objection which Eozoic derives from the doubtful nature of the Eozoum.'[2]

Dana unquestionably proposed the term Archean to include the

[1] 'Green Mountain Geology. On the Quartzite.' *Amer. Jour. Sci.*, series iii., vol. iii., 1872, p. 253. [2] *Ibid.*

great mass of pre-Palæozoic sedimentary rocks as well as the basal schists; and we may take it that if one name is to be given to all the pre-Palæozoic, then one of Dana's two names, Archean or Archæozoic, has unquestionably strong claims for acceptance.

In recent years there has been a widely felt tendency to divide the pre-Cambrian rocks into two divisions—an upper division of non-foliated sediments and a lower division of schists and gneisses to which the term Archean is sometimes restricted. Sir A. Geikie,[1] for example, notes the proposal to reserve Archean for the igneous rocks and Algonkian for the pre-Cambrian sediments.

As an example of another twofold arrangement may be quoted the classification in Chamberlin and Salisbury's Geology:—

Proterozoic (Algonkian)	Keweenawan. Animikean = Upper Huronian of some authors. Huronian.
Archæozoic (Archean complex)	Great Granitoid series (Laurentian) (mainly intrusive). Great Schist series (Mona, Kitchi, Keewatin, Quinnesseo, Lower Huronian of some authors).[2]

Chamberlin and Salisbury object to the names Algonkian and Archean for the primary divisions, on the ground that the names suggest that the divisions are systems, such as Cambrian, instead of being groups, such as Palæozoic.

The Witwatersrand System may be the South African equivalent of these non-schistose pre-Cambrian sediments; and the Swaziland System, or whatever name be adopted for the schists, would represent the Archean. There seems a tendency to adopt the term Algonkian for the non-schistose pre-Cambrian sedimentary rocks, though it was founded to include the schists as well; and a term of world-wide application is wanted for such unaltered pre-Cambrian sediments as the British Torridonian and Longmyndian, the North American Keweenawan, the Scandinavian Sparagmites, the Indian Purana, &c. These rocks appear to represent a geological system between the underlying schists and the beginning of the Palæozoic.

Chamberlin and Salisbury's classification inverts the use of the word Archæozoic, which was proposed by Dana in 1872 pre-eminently for the pre-Cambrian rocks which might be proved to contain life. He introduced the term Archean and Archæozoic when describing one of the quartzites, clearly showing that he included the sedimentary as well as the schistose series in the Archean.

The term Proterozoic was first suggested by Emmons, and rejected by Irving in 1888. He then proposed to limit Archean to the basal schists, and called the overlying sediments Eparchean, as being upon the Archean or Agnotozoic.[3]

[1] *Text-Book*, vol. ii., p. 904.

[2] Chamberlin and Salisbury, *Geology*, vol. ii., p. 160.

[3] R. D. Irving, 'On the Classification of the Early Cambrian and Pre-Cambrian Formations.' *Seventh Ann. Rep. U.S. Geol. Surv.*, 1885–86, p. 454.

Van Hise, however, in 1892 [1] preferred Proterozoic for the upper sedimentary division, and Archean for the lower crystalline division. His Proterozoic was, therefore, equivalent to the Archæozoic of Dana.

If priority is to count for anything in this matter, and the name of the pre-Palæozoic division is to end in ozoic (to conform to the other three), then Archæozoic should be adopted for the pre-Cambrian sediments; and this use agrees better with the natural meaning of the term, for these sediments have traces of an archaic life, whereas the older crystalline schists have none. The basic complex below may still be appropriately called Azoic, as they have not yet given any certain signs of life.

An alternative explanation that might temporarily meet the case for South Africa would be to retain Dana's term Archæozoic for all the pre-Palæzoic rocks, including both the Witwatersrand System and the Swaziland System or basal complex.

Two members of the Committee recommend the adoption of the term Archean for all the pre-Palæozoic. One (Mr. Molyneux) prefers the term Azoic, and Dr. Molengraaff pre-Palæozoïc. Dr. Hatch and Dr. Corstorphine in their work on the Geology of the Transvaal both use the term Archean as exclusive of the Witwatersrand System; whereas Dr. Rogers, Professor R. B. Young, Mr. Molyneux, and Dr. Molengraaff think the term Archean should be abandoned from South African geology. Dr. Rogers groups all the pre-Devonian rocks as the pre-Cape rocks, a course which, though safe, is purely provisional.

II. The Nomenclature of the Upper pre-Devonian Divisions.

1. *Vaal or Ventersdorp System.*

Above the Witwatersrand System is a series of igneous rocks of the Vaal River, which has been called the Vaal River System by Molengraaff and the Ventersdorp System by Hatch and Corstorphine. The votes recorded on this question are five in favour of the name Vaal and five in favour of the name Ventersdorp. Professor Schwarz says the system should be omitted altogether, as it is composed solely of volcanic rocks; and Dr. Rogers and Mr. Mennell agree with Professor Schwarz. This group of rocks can hardly be called a system in the sense in which that word is defined by the International Congress, namely, one of the primary subdivisions of the Palæozoic, &c., such as Silurian or Jurassic.

Three of the representatives of the Transvaal favour the Ventersdorp System, two of the representatives of Cape Colony favour the Vaal System and one the Ventersdorp System. Mr. Molyneux, from Rhodesia, is in favour of the Ventersdorp System. The votes on this question are so evenly divided that it is hardly likely that any agreement will be reached immediately.

[1] *Bull. U.S. Geol. Surv.*, No. 86, p. 509.

2. *Potchefstroom or Transvaal System.*

For the rocks overlying the amygdaloids there is again a choice between two terms, and this question mainly concerns the geologists of the Transvaal.

The name Transvaal System is supported by eight votes, against three for the name Potchefstroom System, so that in this case there is a strong majority of the Committee in favour of the adoption of the older name, the Transvaal System. As the rocks are widely distributed in the Transvaal, and as they give rise to some of the most characteristic features in the State, the name is perhaps not unsuitable. The name Potchefstroom has the advantage of fixing a more precise type locality. There are certainly great disadvantages in the use of the name of a State as that of a geological system, for the ambiguity (some Transvaal rocks not being Transvaal rocks) must frequently be inconvenient. Hence the term Potchefstroom System would probably occasion less inconvenience, but the choice between these two terms will, no doubt, be settled by the practice of geologists in the Transvaal.

3. *The Waterberg System.*

The last of the proposed systems for pre-Karroo rocks is that for the Waterberg sandstone. There is practical unanimity that these rocks should be regarded as a distinct system and called the Waterberg System.

The age of the amygdaloids, the Transvaal and Waterberg Systems, is unquestionably doubtful. The Waterberg System lies unconformably upon the Transvaal System, and that is unconformable upon the amygdaloids, which are in turn unconformable upon the Witwatersrand System. None of the rocks contains fossils. The Waterberg System is, however, regarded with much plausibility as the inland representative of the Cape System, and the Cango beds of the southern part of Cape Colony may represent the Transvaal System. If so, then the Waterberg System would be Devonian, the Transvaal System and the Vaal River, or Ventersdorp amygdaloids be Lower Palæozoic (Silurian, Ordovician, or Cambrian).

III. The Karroo System.

The classification of the Marine Devonian beds does not involve much inter-State difference of opinion, as the marine beds occur only in Cape Colony and Natal. The Karroo System is of wider extent, but there is less disagreement and overlapping in nomenclatures than with the unfossiliferous pre-Devonians. The classification recommended by the geologists of Cape Colony is as follows:—

Karroo System	Stormberg Series .	Drakensberg beds. Cave sandstone. Red beds. Molteno beds.
	Beaufort Series	—
	Dwyka Series	—

Representatives of the Karroo Series in Rhodesia were arranged as follows by Mr. Molyneux in 1907:—

Cape		Bechuanaland Protectorate	Rhodesia	
			Sabi and Limpopo Valleys	Zambesi Valley
Karroo System		Dolerites . .	Tuli lavas and Pipe amygdaloids	Batoka basalts and Dolerite sheets
	Stormberg	Fine sandstones at Klaballa	Samkoto series .	Forest sandstones
	Beaufort .	Tswapong grits.	—	Escarpment grits
	Ecca .	—	—	Upper Matobola Busse beds Lower Matobola Fine fissile sandstones

This sequence is so different from that of the southern States that at present it would be premature to suggest a detailed correlation, and no inconvenience arises from the use of the independent classification.

The classification for Natal, adopted by Mr. Anderson in his final Report (1907), is as follows:—

Upper Karroo . .	Plateau basalts, top Drakensberg and Rhyolitic series of the Lebombo Range in Zululand. Cave sandstones, Drakensberg. Red beds, Drakensberg. Stormberg series, Drakensberg.
Lower Karroo . .	Beaufort beds. Ecca series { Upper, coal-bearing series. / Lower, shales (glacial). Ecca glacial conglomerate (Dwyka).[1]

There has been no representative of Orangia on the Committee, and the representatives of the Transvaal have not called special attention to the classification of the Karroo beds, which have not yet received as much attention in the Transvaal as in the other States.

The Committee have received an interesting report from Professor Broom as to the correlation of the rocks of the Karroo, and the evidence quoted makes it clear that part of the system is to be correlated partly with the Permian and partly with the Lower Mesozoic (Trias and Jura).

[1] W. Anderson: Third and Final Report of the Geological Survey of Natal and Zululand. Natal Surveyor-General's Department, London. 1907, p. 36.

APPENDIX I.

Member of Committee	Name for pre-Palæozoic	? 1 or 2 or more divisions of pre-Palæozoic	? Recommend such combination as Archean and Algonkian or Proterozoic and Archæozoic	? Abandon name Archean from South African Geology	? Adopt Swaziland System	? Witwatersrand System	? Vaal or Ventersdorp System	? Potchefstroom or Transvaal System	? Adopt Waterberg System
Sir T. H. Holland	Purana or some local name. Archean	Two	Purana or some local name, and Archean	No	Yes, as a local name for the Archean	Yes	No Vote	No Vote	No Vote
F. H. Hatch	—	—	—	Abandon	Yes	Yes	Vent.	P.	Yes
G. S. Corstorphine	—	—	—	—	Yes	Yes	Vent.	P.	Yes
H. Kynaston	—	—	—	—	Yes	Yes	Vent.	T.	Yes
R. B. Young	Not urgent		—	Abandon	Yes	Yes	Vaal	T.	Yes
A. Young	Premature		Premature	—	No	Yes	Vaal	T.	Yes
A. W. Rogers	Nothing certain	pre-Devonian	—	Abandon	No	Yes	Vaal	T.	Yes
E. H. L. Schwarz	—	—	—	—	Barberton System	—	Neither	—	—
R. Broom	Archean	One	—	No	No	Yes	Vent.	T.	Yes
W. Anderson [1]	—	—	—	No	Yes	Lower Transvaal	—	—	—
A. J. C. Molyneux	Azoic	Premature	—	Abandon	No	Yes	Vent.	T.	Yes
G. A. Molengraaff	pre-Palæozoic	One	Premature	Abandon	Yes	Yes	Vaal River	T.	Yes
W. Gibson	Archean	Two	Algonkian for sediments. Archean for basal complex	No	Yes	Yes	Vaal	P.	Leave to South African geologists
F. P. Mennell	Archean	—	Prefer Huronian to Algonkian	No	No	Shorten to Rand System	Neither. Agrees with Schwarz	T.	Yes
J. W. Gregory	Archæozoic	Two	Purana, Torridonian, or some such term, and Archean	No	Yes	Yes	Vaal as name of a series	P.	Yes

[1] Adopted from his final Report on the Geology of Natal.

APPENDIX II.

Report by Professor R. Broom.

I fear it is premature to decide on a general term for pre-Devonian rocks. Archean seems a natural term for the lowest rocks, but, as you define it, it becomes impossible. The Malmesbury beds are by no means always schists. Clay slate is the general thing, and much of it has very little mica. Here and there bands of limestone are met with, not apparently greatly altered. Some South African geologists are of opinion that the Malmesbury is not so very old, and many beds look so fresh that one cannot resist the temptation to look for fossils, and occasionally things turn up that have an organic look, but nothing determinable has been got. At any rate, it is just possible that Malmesbury may be Cambrian, though I think all the evidence is in favour of its being very much older. Still, there is a doubt, and I fear we cannot use Archean for it. In the meantime I am quite agreeable to drop Archean, and I do not think Algonkian any better. Take the Dolomite. This, according to the suggestion, would be Algonkian, but there seems a probability that it is not older than Cambrian. I object to Swaziland System being used for all the older beds, because there is no evidence that Malmesbury beds, Namaqualand, are of the same age. The evidence is rather the other way.

I object to 'Vaal River' as a bad term for a formation. 'Vaal' is worse. As well speak of the 'Fawn' formation. Some English scientists sometimes forget that the words they use are very ordinary Dutch words.

The same objection and others might be urged against 'Table Mountain Series.' The name is too long and out of harmony with other geological names. I should prefer 'Tafelberg Series' or 'Tafelbergian,' which would be in harmony with 'Witteberg' and 'Stormberg,' but 'Table Mountain' seems too firmly established. 'Transvaal System' seems by far the best name. 'Potchefstroom' is frightful.

Report by Dr. F. H. Hatch.

Since I am not in complete accord with some of the statements in Professor Gregory's report, perhaps I may be permitted to state briefly my own views on the subject which forms the terms of reference to the Committee.

The oldest beds in South Africa known to be fossiliferous are those of the Cape System, and the fossil evidence shows them to be of Devonian age. Since, at the Cape, the Dwyka Series is in conformable relation with the uppermost division of the Cape System (the Witteberg beds) and the same series unconformably overlies the Waterberg sandstone in the Transvaal, the latter must be older than the Witteberg beds; that is, it must be either equivalent to the lowest division of the Cape System (the Table Mountain sandstone), or it must be still older. It follows that the underlying systems in the Transvaal—the Potchefstroom (or Transvaal), the Ventersdorp, the Witwatersrand, and the Swaziland Systems—must be all older than the Devonian. I have

shown elsewhere [1] that, without making any allowance for the great intervals between the Waterberg and the Potchefstroom (or Transvaal) Systems, between the Potchefstroom and the Ventersdorp Systems, between the Ventersdorp and the Witwatersrand Systems, and between the Witwatersrand and the Swaziland Systems, there are, reckoning from the base of the Waterberg and the top of the Swaziland Systems, at least 45,000 feet of strata; while the thickness of the Swaziland beds, which is, of course, very great, is unknown.

The Swaziland System consists largely of crystalline schists with intrusive granite-bathyliths, and this, taken together with the fact that it lies below three big pre-Devonian Systems of strata, each separated from the one above it by great discordances, makes it not unlikely that this system represents the Archæan, or a portion of the Archæan, of other countries. But since, after all, we only know with certainty that it is pre-Devonian, it would be better for present purposes to eliminate the use of the word Archæan from South African geology altogether. The same reasoning applies to the suggested introduction of such terms as Algonkian and Archæozoic.

As to the Witwatersrand, the Ventersdorp, and the Potchefstroom (or Transvaal) Systems, any attempt at correlation with the systems of other countries is, in the absence of fossil evidence, out of the question.

Coming now to nomenclature, the name Witwatersrand System is now generally accepted. With regard to the Ventersdorp System, this name was proposed by myself [2] for a formation, comprising boulder beds, conglomerates,[3] volcanic breccias and lavas, and totalling at least 8,000 feet, which unconformably overlies the Witwatersrand System, and is itself transgressively overlain by the Black Reef Series, or lowest beds of the Dolomite Series. The name appears to me decidedly preferable to Vaal River System, since the latter is apt to lead to a confusion between the topographical expression, 'River System,' and the stratigraphical term. Ventersdorp System has, moreover, the priority.

With regard to 'Potchefstroom System' *versus* 'Transvaal System,' the latter term is the older; but since the use of the name of a country for a system, which, after all, plays only a minor *rôle* in its geological structure, seemed as objectionable as if the Devonian System of England had been called the 'English System,' Dr. Corstorphine and myself proposed that 'Transvaal System' should be abandoned in favour of 'Potchefstroom System,' all three members of the system being developed in the district of that name, and the nomenclature being in conformity with that used in the Witwatersrand, Ventersdorp, and Waterberg Systems.

The term 'Lydenburg System' would have been eminently suitable but for the fact that Dunn had previously used it to include not only

[1] Presidential Address to the Geological Society of South Africa for the year 1906. *Minutes of Proceedings, Geol. Soc. South Africa*, 1906, vol. ix.

[2] F. H. Hatch: 'The Boulder Beds of Ventersdorp,' *Trans. Geol. Soc. South Africa*, vol. vi. (1904), p. 95. 'Vaal River System' was proposed by Molengraaff in the English edition of *The Geology of the Transvaal* (1904), p. 19.

[3] Prof. Schwarz is incorrect in saying that this is a volcanic series only, for it includes boulder beds, conglomerates, and sandstones of sedimentary origin (Elsburg Series).

the beds in question, but also everything down to the Namaqualand schists (*i.e.*, the Swaziland System).

Report by Sir T. H. HOLLAND.

I send herewith some notes which I have hurriedly written regarding the questions which you ask in your circular to the Committee on South African stratigraphy. It is difficult for me to say exactly how much of my Indian experience is of value to you, and it would be much more satisfactory, although I see that it is impossible, for the Committee to meet and fight out the undetermined questions. From my point of view, I have no right to vote on any question except the wide one of retaining the term Archæan. For the rest, my remarks are no more than suggestions to those who have the requisite local knowledge.

I am in favour of making two divisions for the pre-Palæozoic rocks, and would suggest the retention of the term Archæan for the basement complex of schists and gneisses. The Swaziland series of the Transvaal and Natal appear to be essentially similar in lithological characters to those of America included in the Archæan.[1] Their stratigraphical position being in agreement with their lithological characters, they have as much right to be regarded as Archæan as have the formations so named in Europe, and the one point to remember is the fact that the term Archæan is expressive to the geologist, although no one could prove that the Archæans of America, Europe, and South Africa are contemporaries. The Swaziland Series bears a relation to the younger rocks very similar to that existing between Lawson's Ontarian group and the Animikies, and a similar relation exists in India between the Dharwars and associated gneisses and schists, on the one hand, and the unfossiliferous Cuddapahs and Bijawars, on the other.

There is no justification for the recent American mutilation of Dana's term Archæan; the gneissose granites, granitoid gneisses, and schists are not necessarily older than the Huronians of the typical area, and sometimes probably they are younger. The separation of the granitoid types on the assumption that they possibly represent parts of the primitive crust has no scientific foundation, for there may never have been a primitive crust in the sense assumed in so many text-books that accept the Nebular Hypothesis as an unimpeachable gospel. Possibly rocks of the Huronian type, including even the conglomerates, were formed long before the growth of the globe noticeably ceased, and it therefore seems best to draw a group boundary line at the great Eparchæan interval which appears to be so world-wide. Below this line are schists of all sorts, of sedimentary as well as of igneous origin, closely folded and foliated; above this line, on such stable *Horsts* as the Great Lakes region in America, the central and southern parts of Africa, and the Peninsula of India, there are old, generally unfossiliferous, probably in all cases pre-Cambrian, rocks that are sometimes unaltered, sometimes folded locally, and sometimes metamorphosed locally, but not gathered into close folds with gneisses and schists.

In peninsular India I propose to retain the name Archæan for

[1] *The Geology of South Africa*, 1905, p. 1

the gneisses and schists, including many of obviously sedimentary origin. Some of these, distinguished as the Dharwars in the south, and as Aravallis, Champaners, and other local series in the north, recall many of the features of the Lower Huronians of Canada and of the Swaziland series in the Transvaal; hornblende-, chlorite-, and the talc-schists interbedded with quartz-hematite and quartz-magnetite schists and, rarely, crystalline limestones, are common types in these formations. It is impossible to regard the closely folded Dharwars as having been laid down on the exposed surfaces of the gneisses near by, when the latter often show little more in the way of deformation than might be regarded as flow structures developed during consolidation. Yet gneissic pebbles are sometimes found in the Dharwar beds, though some of these, at any rate, are doubtfully true conglomerates.

Some of the gneissose granites, indistinguishable from typical Archæan gneisses, are certainly younger than some Dharwars, and generally it is impossible to unravel the mixture by any classification dependent on age. It is, therefore, far more convenient to group all such highly foliated rocks in peninsular India as Archæan. The name involves no idea other than great age, and, has, therefore, none of the objections that might be offered to such terms as Azoic, Eozoic, and Archæozoic.

I do not see how the term Archæan can give rise to confusion in South Africa, and it certainly does convey to the geologist the idea that there exists a collection of very ancient rocks which have their nearest probable equivalents among the Archæan of North America, India, and other parts of the earth's surface where complications have not arisen by post-Cambrian folding. There appears to be no call for the manufacture of a local term in South Africa or in India; our so-called Archæan rocks may not be of the same age as those of America, but they have the same relative position in the scale, the same characters, and, with the perspective due to this distance of time, we are justified in regarding all obviously Archæan rocks as equivalent.

Algonkian or Proterozoic.

For the oldest rocks preserved after the great Eparchæan interval I propose to use the term Purana in India.[1] The name means more than merely old, for the Puranas, although very old in Indian literature, are not the oldest; they are a *réchauffé* of the more ancient Hindu literature—the alluvial products derived from the basement complex of the Archæan Vedas. Before the term Purana was suggested we had numerous local names for the old unfossiliferous formations resting on the Archæan gneisses and schists—Cuddapahs, Bijawars, Gwaliors, Pengangas, Chilpis, Kurnools, Kaladgis, Bhimas, and Vindhyans. We have no positive evidence for the age of these rocks beyond the limits Archæan below and about Middle Carboniferous above, the latter limit being that determined by the base of the Talchir stage of the Gondwana System. The Puranas may be wholly or in part pre-Cambrian in age,

[1] Holland: Presidential Address, *Trans. Min. and Geol. Institute of India*, vol. i., 1906, p. 19.

but they appear to be divisible into two divisions which certainly recall many of the features of the Animikies and Keweenawans of the Great Lakes region in North America, and although, in default of evidence to the contrary, it is probable that they are mostly pre-Cambrian, it is possible that the Upper Vindhyans were formed since the days of *Olenellus*. One cannot help being reminded by the Upper Vindhyan red sandstones of the Cambrian purple sandstones of the Punjab Salt Range, and, because of the way they rest on old unfossiliferous rocks of great thickness, of the Potsdam sandstones of America; but these obvious temptations have to be resisted, for we have not only no fossil evidence, in spite of apparently perfect conditions in the shales and marls, but no definite periods of folding that could give a clue of correspondence with the periods of marked folding in Europe. The term Purana is thus of local value and cannot be offered except temporarily to assist South African geologists.

The term Algonkian, however, has still less claim to be used in South Africa, and, after the mutilation it has undergone in America, it might be dropped with advantage there also. The term Proterozoic implies conditions that have yet to be established with certainty and is thus also unsuitable. I would suggest, therefore, that a local term be used in South Africa for the post-Archæan, pre-Palæozoic rocks. A term corresponding to Purana might be suggested by someone conversant with the local languages; otherwise a geographical term would have to serve. The term Eparchæan should be confined to the great interval between the Archæan and the oldest of the Witwatersrand System, for we should not forget that the intervals of no record are as important almost in the history of the world as the periods of sedimentation, and the interval between the formation of the Swaziland schists and the Orange Grove quartzites may have been as great in time as that which has transpired since *Olenellus* lived.

It would not assist the question to point out the lithological similarities between the Witwatersrand, Ventersdorp, and Potchefstroom (Transvaal) Systems and the Purana rocks of India; for if the Indian term were used in South Africa it would be liable there, as here, to decapitation on the discovery of fossils in the higher beds. One cannot help noticing, however, the similar 'calico rocks,' the jaspers, and the great trap-flows that are prominent in our older Puranas, and the dolomitic, 'Olifantsklip' limestones in parts of the higher beds. Notwithstanding its obvious objections, I would rather use the term Purana in South Africa than the term Proterozoic; the establishment of further correspondence with India is likely to be of greater value to geology than would be the study of fancied resemblances between South Africa and the Northern Hemisphere in Europe and America.

Transvaal Questions.

6. I vote for the retention of the term Archæan.

7. Swaziland Series seems unnecessary, unless it can be used for the separation of the compact lithological series corresponding to the Huronians (Lower Huronians) of America and Dharw[illegible] of India.

8 to 11. I have no right to vote on the relative value of alternative local terms.

In a subsequent letter, June 11, Sir T. H. Holland adds the following:—

'It is not exactly correct to state that the Witwatersrand System would be the South African equivalent of the American Algonkian, as this term is employed in America to include, besides the comparatively unaltered Keweenawan and Animikie Series, the foliated and closely folded (Lower) Huronians. The use of a system name to straddle across one of the greatest breaks known, namely, that between the (Lower) Huronians and the Animikies, is enough to condemn the term; but, as it has been used so commonly in this way, it would be impossible now to use the term in South Africa; for the Swaziland Series, according to Hatch and Corstorphine,[1] evidently includes rocks that would be included in the American Algonkian. If the term Algonkian had been made to extend from the base of the Cambrian to the epi-Huronian, infra-Animikie unconformity, it would have had an extended use in stratigraphy; but it is too late now to change its meaning. If, therefore, no suitable local term can be devised for the pre-Palæozoic rocks lying unconformably on the Swaziland schists and gneisses, the Indian name Purana might be borrowed; it covers all old unfossiliferous rocks (in part or wholly pre-Cambrian) down to the base of the oldest rocks resting unconformably on the gneisses, schists, and closely folded, metamorphosed Dharwar (Lower Huronian) Series.

'For all rocks below this great break I use the term Archæan in India, and, although this use of the term is not exactly that proposed by Dana (who evidently intended originally to include the unmetamorphosed pre-Palæozoic sediments), it corresponds to the recognised use of the term in Canada, and to the meaning adopted by Van Hise in his memoir on the "Iron-Ore Deposits of the Lake Superior Region" (21st Ann. Rep. U.S. Geol. Surv., Part III.); that is, after he had published other views in his well-known Bulletin No. 86 on the Archæan and Algonkian.[2]

'It is true that local unconformities between the (Lower) Huronian (Dharwarian of India) and the older gneisses are shown by conglomerates, and possibly in time the Archæan may be subdivided locally to recognise these. But, although these conglomerates, that include pebbles of gneiss, indicate a pre-existing gneissose series, there are many granitoid gneisses in the complex that are younger than the associated Dharwars (and—Lower—Huronians). Hence it is possible to split up the Huronian-Laurentian (Archæan) complex only locally, and this fact should be contrasted with the great widespread unconformity above the group composed of the basal complex and (Lower) Huronian (Dharwarian) rocks.

'Lithologically the Dharwars in India can be distinguished from the more crystalline gneisses and schists with which they are folded, just as the Huronians (Lower Huronians) can generally be separated from

[1] *Geology of South Africa*, 1905, p. 101.
[2] [Disc]ussion by C. K. Leith, *Journ. Geol.*, x., 1902, p. 894.

the Laurentians; but no one can say that the Huronians are *all* younger than *all* the rocks that would be readily ascribed to the Laurentian. Nor in India would it be right to say that the Dharwars are, as a whole, younger than many large spreads of granitoid gneisses, which our earlier workers readily assumed, in conformity with the prevalent views of the time, to be older. Evidently, also, among the Swaziland and Namaqualand Series there are many altered clastic rocks that retain enough of their original chemical (if not physical) characters to be distinguishable from the gneisses and granitoid rocks of the fundamental complex. These might be distinguished lithologically under local names; but the whole mass of closely folded and foliated rocks ought to be placed together in one group: for this group the name Archæan might be conveniently used, in spite of the fact that in its original sense it would cover the Witwatersrand beds, and in spite of the fact that its meaning has since been restricted by many American authors to the gneissose rocks of the basal complex. Clearly, if our terminology is to express stratigraphical history, the epi-Swaziland unconformity should be recognised as a great dividing line; all below should be in one group, and for this group I would use the name Archæan; all pre-Palæozoic rocks above should be given another group-name, either a local name or Purana.

'I have already lodged objections against terms like Azoic, Eozoic, Archæozoic, and Proterozoic; you might at the same time have led to the slaughter such terms as Hypozoic, Prozoic, and Pyro-crystalline; Chamberlin and Salisbury have spoilt the chances of perpetuating their group-names by inverting the meaning of the term Archæozoic as proposed by Dana. They have also unfortunately drawn a group-boundary line between the Huronian and the Schist Series, at the same time including within their Proterozoic group an interval probably long enough to be regarded as an æon. We cannot now use the term Archæozoic for pre-Cambrian sediments and Azoic for the complex below. The use of the term Archæan that I have suggested corresponds with the classification adopted by Hatch and Corstorphine. I have offered to lend the term Purana for the pre-Palæozoic sediments above the Swaziland Series, as the term has been kept from the changes of meaning to which Algonkian has been subjected by the Americans.

'Before you close your report, may I suggest that you should read again G. M. Dawson's Address to Section C at Toronto in 1897? He there shows how the use of the term Huronian for the sedimentary rocks now known to the Canadian Survey as Animikie arose through a clerical error in describing the geographical distribution of Logan's typical Huronian. Unfortunately the rocks, thus indicated by mistake in the typical Huronian, are well exposed in a very accessible part of the lake shore, and thus a large number of geologists have gathered their ideas of the Huronian in a way that would not have been possible if these wrongly included exposures were in a very inaccessible region. You will remember that the break between the Huronian proper and the Animikie Series, on which Dawson laid so much stress, was also noticed by Van Hise in his paper on "An Attempt to Harmonise some apparently Conflicting Views of Lake Superior Stratigraphy" (*Amer. Journ. Sci.*, Series iii., vol. xl. 1891, pp. 117-137). Van Hise observed the importance of this great break too late [illegible] to enable

him to rearrange his ideas for his Bulletin No. 86, and it was only afterwards, when writing his memoir on the Lake Superior Iron-Ores, that he broke loose from the American Survey traditions and grouped together in the Archæan the sedimentary iron formations of Vermilion and Marquette, which he had formerly placed in the Algonkian.'

Report by Mr. H. Kynaston.

Older Rocks.

While fully admitting the desirability of securing greater uniformity of geological nomenclature between the different colonies, I consider it inadvisable at present to introduce names of European or American groups and systems into South African geology, except for purposes of comparison and correlation. These can be clearly defined in the Northern Hemisphere, but are not so suitable for South African stratigraphy, even if the ages were known of all the South African formations. For example, the Karroo System includes a practically uninterrupted succession of beds, which can be correlated with strata ranging from the Carboniferous to the Jurassic.

With regard to the term Archæan, there is not so much objection to this as there is at present to the use of such strictly defined terms as Palæozoic, Mesozoic, &c., provided it is employed in its wide sense. If so used, it might provisionally include all rocks older than the Witwatersrand System—*i.e.*, the older granites, the Swaziland sedimentary beds (Moodie's series in the Eastern Transvaal and Kraaipan formation in the West and Bechuanaland Protectorate), and the basal gneissic and schistose complex. It would be unwise to include the Witwatersrand System also in the Archæan, as we do not yet know whether this may not correspond to part of the early Palæozoic.

Ventersdorp System.

The rocks included in this system have not yet been properly surveyed or classified in the Transvaal, but they should certainly rank as a separate system, since there is a marked break both above and below them, and they include sedimentary as well as volcanic rocks, both in the Transvaal and Cape Colony (Bechuanaland and Griqualand West). In the north of the latter colony they have been subdivided into three series, which are probably also developed in the western Transvaal.

Transvaal System.

We consider this to be a suitable term, which should be retained, especially since it is now generally in use in South African geological literature, for the Black Reef, Dolomite, and Pretoria series, the equivalents of which in northern Cape Colony are as follows, in descending order:—

Pretoria series . .	Griqua Town series. [The Ongeluk volcanic series, or Middle Griqua Town beds of Rogers, are probably represented by the basic amygdaloidal lavas in the middle of the Pretoria series.]	
Dolomite series . .	Dolomitic limestones of	Campbell Rand series.
Black Reef . .	Basal quartzites of	

The Waterberg System.

According to the detailed work of Mr. Mellor in the Middelburg district this system may be subdivided as follows:—

		N. Cape Colony
Upper	Sandstone and quartzite series	Upper Matsap beds.
Lower	Shale and sandstone series Volcanic series, with interbedded shales and sandstones	Probably Middle (volcanic) and Lower Matsap.

The Sijarira and Umkondo series of Rhodesia may very probably be the equivalent of the Waterberg System.

Karroo System.

With regard to the classification of this system, we consider that that of Cape Colony should be followed as far as possible, as it is there that the system has its maximum development; also it is important to distinguish clearly between the glacial and non-glacial beds, between which there is apparently in the Transvaal a slight unconformity. We also approve of the proposal of the Cape Colony members of the Committee to abandon the term Ecca and extend that of Beaufort to include the Ecca. The term Dwyka, however, should be retained to include the beds of glacial origin at the base of the system.

The following table represents the Karroo System as developed in the Transvaal, with the probable Cape Colony and Rhodesian equivalents:—

Karroo System.

Volcanic series	Lebombo rhyolites	(absent)	Stormberg series	
	Bushveld amygdaloids	Volcanic group	Stormberg series	Tuli amygdaloid and Batoka basalts.
Bushveld sandstone series	Fine red and yellow sandstones	Cave sandstone	Stormberg series	Forest sandstones, Samkoto series and Klaballa sandstones of Bechuanaland Protectorate.
	Sandy marls and shales	Red beds	Stormberg series	
		Molteno beds ?	Stormberg series	
Coal-measure series		Beaufort series		Coal-measure series (including escarpment grits, Matobola and Busse beds).
(Slight unconformity)		Ecca (practically absent in Transvaal),		
Glacial conglomerates and shales (Dwyka)		Dwyka series		Glacial conglomerates.

Report by Mr. F. P. Mennell.

Re the South African Correlation Committee, I beg to submit the following notes, suggestions, and criticisms on Professor Gregory's draft

On page 124, under *b*, the reference to 'mica schists,' &c., might well be omitted, as the South African rocks are almost exclusively horn-blendic and usually massive.

Re Swaziland System, there is no evidence whatever of its relationships to the rocks of other parts of South Africa, and, moreover, where are we to find a reliable and detailed field and petrographical account of the typical area to provide a basis for comparison? The Malmesbury beds are far more likely to be equivalent to the Rand group than to the Swaziland series, provided the latter do not prove to be metamorphosed representatives of the former.

Re term Archæan, it should, of course, be used in the comprehensive sense in which it was originally proposed, and include therefore such rocks as those of the Rand. Any divisions of the older rocks should be considered merely as subdivisions (systems) of the Archæan group. The term Algonkian is not very euphonious—Huronian would be far better if such terms are needed, which I doubt. It has also to be remembered that, barring a few doubtful 'Basement schists,' in Rhodesia, at least, all the crystalline 'basal complex' are altered igneous rocks intrusive in the schists of sedimentary origin. The same fact was accepted by the International Conference of the United States and Canadian geologists, I notice, lately, for the relations of the Laurentian and Huronian rocks.

Re other matters, why not shorten 'Witwatersrand' to the far more euphonious 'Rand,' which everybody really uses? I agree with Professor Schwarz *re* the Vaal River or Ventersdorp series; as igneous rocks they have no claim to the rank of a separate system. I must confess, indeed, that I do not like to use names for 'systems' which are unknown to other parts of the world, though we must, of course, have local names for purely local purposes.

I consider it premature to subdivide the Rhodesian coal-beds, as the divisions made by Mr. Molyneux at Sengwe cannot be recognised even at Wankies, which is a very short distance off, as things go in South Africa. There also appear to me the strongest objections to including the Forest sandstones even provisionally among the Karroo beds, though the latter do appear to include nearly the whole Mesozoic period. The Forest sandstones are apparently separated by a great unconformity from the underlying upper beds of the Coal series (presumably Upper Beaufort, or even later), and it is not very clear either that they do not include beds of very different ages. It may be noted that the red beds of the Forest sandstones occur above the basalts, or, in rare cases, intercolated between them.

The following is the Rhodesian sequence as at present known:—

Somabula gravels and sands	? Tertiary.
Forest sandstones with interbedded basalts	? Cretaceous.
Coal series (=Beaufort and Ecca beds)	Permian.
Sandstones (? Waterberg)	? Lower Palæozoic.
Dolomite	—
Conglomerate series, with interbedded lavas	Archæan (with intrusive granites, &c.).
Banded ironstone series	
? Basement schists	

Report by Dr. A. W. Rogers.

I think the result of the discussion is chiefly of value in showing how we stand in these matters, though I am very sorry that all the trouble you have taken has not produced the unanimity you would like.

I think you are inclined to overestimate the present value of our knowledge of South African geology. One great defect is the want of information as to the relative ages of the large granite intrusions. If we could say with certainty that the Cape Town, Namaqualand, Gordonia, Bechuanaland, and Transvaal (old) granites were of one age, I would gladly agree to the term Swaziland System for all older sedimentaries; but this is not the case, and the N.W. Cape area is too little known to allow the matter to be fairly discussed. In ten years' time, perhaps, we shall be better off.

Both du Toit and I are at the present moment much exercised—both in leg and mind—on this granite question. We do not agree on all points, but that is not from any motive but a desire to get to the bottom of it. I do not like to throw whatever weight my decision would carry into one scale at present.

I think Schwarz's scruples about the Vaal or Ventersdorp System well founded. I think I made a similar sort of remark in Annual Report for 1906, but cannot refer you to the page, as I am in camp in Prieska district. It comes in the section on the Pneil series in a report on Vryberg and Kuruman.

The connections between the Vaal and Transvaal 'systems' is very close, and the unconformities are not limited to the break between the two systems.

Supplementary Report by Dr. Hatch.

Since I wrote the above notes I have spent the best part of a year in Natal, and have had an opportunity of studying the ancient floor of crystalline schists and intrusive granites which there emerges from below the horizontally bedded Karroo and Table Mountain Sandstone formation, and is admirably exposed in the deeply incised valleys of Zululand. The schistose rocks, which are largely of sedimentary origin, are of great variety—dark-coloured hornblende-schists much permeated with aplite and pegmatites, and frequently cut by intrusions of serpentine, occur in the Mpapala, Fort Yolland, and Lower Tugela River districts; mica-schists and kyanite-schists, in the Nkandhla Forest and on the Bobe Ridge; micaceous and chloritic schists, in the Mfongosi Valley; conglomerates, quartzites, quartz-felspar-schists, and sericite-schists, in the Buffalo River and Insuzi Valleys; and magnetite-quartz-schists, jasper-schists, and quartzites, in the Vryheid district.

There is no lithological succession that at all resembles the typical Rand section, and I do not think that representatives of the Witwatersrand System exist in Natal. Nor do I agree with Voit[1] that the hornblende-schists, with their permeation veins of aplite and pegmatite, can be directly correlated with the Lewisian or Laurentian gneiss.

With regard to the red sandstone and conglomerate formation,

[1] *Trans. Geol. Soc. S.A.*, vol. x. (1907) pp. 93, 94.

which, since the days of Sutherland, has been correlated with the Table Mountain Sandstone of Cape Colony, this formation bears the closest resemblance to the Waterberg Sandstone of the Transvaal, and thus lends further support to the correlation of the latter with the Cape formation. If this view be correct, the Matsap beds of Griqualand West, which have been shown by Rogers[1] to be older than the Table Mountain Sandstone of the Cape, cannot be correlated with the Waterberg Sandstone of the Transvaal.

Photographs of Geological Interest.—Seventeenth Report of the Committee, consisting of Professor J. GEIKIE (*Chairman*), Professors W. W. WATTS *and* S. H. REYNOLDS (*Secretaries*), Dr. TEMPEST ANDERSON, Mr. G. BINGLEY, Dr. T. G. BONNEY, Mr. C. V. CROOK, Professor E. J. GARWOOD, Messrs. W. GRAY, R. KIDSTON, *and* A. S. REID, Dr. J. J. H. TEALL, *and* Messrs. R. WELCH, W. WHITAKER, *and* H. B. WOODWARD. (*Drawn up by the Secretaries.*)

THE Committee have to report that since the issue of the last report in 1908 there have been received 410 photographs for the national collection. The total number in the collection is now 5,227, and the yearly average amounts to about 250.

These photographs have been received, acknowledged, catalogued, mounted, and stored at a cost to the Association of 4·6*d.* per print, or, adding the collection of about 453 duplicates, a cost of 4·3*d.* per photograph.

The Geological Survey continues to provide accommodation for the storage of the collection and provides facilities for inspection by the public and work upon the collection by the Secretaries.

The annexed geographical scheme shows the distribution of the new accessions among the counties. Dumbartonshire figures in the scheme for the first time, and notable additions are recorded in the counties of Dorset, Gloucester, Somerset, Yorkshire, Pembroke, Inverness, Galway, Mayo, and the Isle of Man.

The principal contributors this year are Mr. Bingley and Professor Reynolds. The former continues his survey of the Yorkshire coast, and sends also series from Richmond, Leeds, and Pickering. He contributes, moreover, photographs from the Isle of Man and the Welsh borderland. Professor Reynolds gives a set of serial sections taken on both sides of the classical Avon Gorge, and series from Skye and the Dorset coast. In addition, he sends photographs from Hereford, Somerset, Yorkshire, a considerable Welsh series, chiefly Carboniferous and volcanic, and several sets from regions in Scotland and Ireland.

An interesting and beautiful set of Carboniferous and Devonian volcanic photographs comes from Mr. R. Vowell Sherring, and examples taken during excursions of the Geologists' Association by

[1] *The Geology of Cape Colony* (London, 1909), p. 111.

Counties	Previous Collection	Additions (1910)	Total
ENGLAND—			
Cornwall	88	4	92
Devonshire	206	2	208
Dorset	136	38	174
Gloucestershire	84	39	123
Herefordshire	2	3	5
Hertfordshire	20	2	22
Kent	155	6	161
Shropshire	63	1	64
Somerset	122	47	169
Staffordshire	54	2	56
Surrey	69	6	75
Sussex	18	8	26
Yorkshire	888	72	960
Others	1,149	—	1,149
Total	3,054	230	3,284
WALES—			
Carnarvonshire	109	9	118
Denbighshire	16	8	24
Merionethshire	52	1	53
Montgomeryshire	13	4	17
Pembrokeshire	45	18	63
Radnorshire	21	5	26
Others	103	—	103
Total	359	45	404
CHANNEL ISLANDS	38	—	38
ISLE OF MAN	61	41	102
SCOTLAND—			
Argyllshire	36	4	40
Ayrshire	6	16	22
Dumbartonshire	—	4	4
Edinburgh	54	7	61
Inverness-shire	143	34	177
Others	299	—	299
Total	538	65	603
IRELAND—			
Dublin	44	5	49
Galway	33	13	46
Mayo	14	11	25
Others	578	—	578
Total	669	29	698
ROCK STRUCTURES, &c.	98	—	98
Summary.			
ENGLAND	3,054	230	3,284
WALES	359		404
CHANNEL ISLANDS	38		38
ISLE OF MAN	61		102
SCOTLAND	538		603
IRELAND	669		698
ROCK STRUCTURES, &c.	98		98
Total	4,314	410	5,227

Mr. T. W. Reader and Mr. James Parker. Mr. Preston contributes Cornish photographs taken with his usual skill.

Other contributors include Mr. E. S. Cobbold, Mr. A. H. Bassano, Mr. Baldock, Mr. Rodda, Mr. Russell F. Gwinnell, Mr. A. E. V. Zealley, Miss M. S. Johnston, and Miss Hendriks. To all these ladies and gentlemen the Committee owe and desire to tender their thanks.

No important additions have been made to the duplicate series. The slides have been exhibited by Mr. Whitaker to the following, among other Societies: The Battersea Field Club, the Hastings and St. Leonards Natural History Society, the Croydon branch of the Selborne Society, the Holmesdale Natural History Club, the Ipswich and District Field Club, the Tunbridge Wells Natural History Society, and the South Croydon Literary Society.

The Committee note with pleasure the issue by His Majesty's Geological Survey of a first list of geological photographs taken by the staff of that body, and that the issue of a list of photographs taken by the Scottish staff is promised shortly. The Geologists' Association also continues to encourage the taking and registration of geological photographs.

Applications by Local Societies for the loan of the duplicate collection of prints or slides should be made to one of the Secretaries. A descriptive account of them can also be lent. The carriage and the making good of any damage to slides are the only expenses to be borne by the borrowing Society.

The Committee recommend that they be reappointed, that Professor J. Geikie be Chairman, and Professors W. W. Watts and S. H. Reynolds joint Secretaries.

SEVENTEENTH LIST OF GEOLOGICAL PHOTOGRAPHS.

From August 22, 1908, to August 23, 1910.

This is a list of the geological photographs which have been received and registered by the Secretaries of the Committee since the publication of the last Report.

Contributors are asked to affix the registered numbers, as given below, to their negatives for convenience of future reference. Their own numbers are added in order to enable them to do so.

* indicates that photographs and slides may be purchased from the donors or obtained through the address given with the series.

Copies of other photographs desired can, in most instances, be obtained from the photographer direct, or from the officers of the local society under whose auspices the photograph was taken. The cost at which copies may be obtained depends on the size of the print and on local circumsta[illegible] over which the Committee have no control.

The Comm[illegible] *not assume the copyright of any photographs* included in t[illegible] Inquiries respecting photographs, and applications for per[illegible] to reproduce them, should be addressed to the photographer[illegible]ect.

Copies of photographs should be sent *unmounted* to
Professor S. H. REYNOLDS,
The University, Bristol,
accompanied by descriptions written on a form prepared for the purpose, copies of which may be obtained from him.

The size of photographs is indicated as follows:—

L = Lantern size.	1/1 = Whole-plate.
1/4 = Quarter-plate.	10/8 = 10 inches by 8.
1/2 = Half-plate.	12/10 = 12 inches by 10, &c.

E. signifies Enlargements.

ACCESSIONS, 1908-1910.

ENGLAND.

CORNWALL.—*Photographed by* HAROLD PRESTON,* *Alverne House, Penzance.* 1/1.

Regd. No.		
4801	(12) Perranuthnoe, Mounts Bay .	Marine erosion of cliffs of 'head.' 1908.
4802	(13) Trevene Cove, Perranuthnoe, Mounts Bay.	Raised Beach. 1908.
4803	(14) Pornanvon Cove, St. Just .	„ „
4804	(15) „ „ .	„ (near view). 1908.

DEVONSHIRE.—*Photographed by* F. T. BLACKBURN,* *Budleigh Salterton. Presented by* E. S. COBBOLD, *F.G.S.* 1/2.

4805	( ) Budleigh Salterton. . . .	Pebble Bed, faulted. 1909.
4806	( ) „	Pebble Bed and false-bedded Sand. 1909.

DORSETSHIRE.—*Photographed by* Professor S. H. REYNOLDS, *M.A., F.G.S., The University, Bristol.* 1/4.

4807	(06, 100) Black Nore Point, Portland Isle.	Portland Stone underlain by Portland Sand. 1906.
4808	(06, 101) Black Nore Point and neighbouring cliffs, Portland Isle	Cliffs of Portland Beds capped by Purbeck. 1906.
4809	(06, 102) Black Nore Point and neighbouring cliffs, Portland Isle	Cliffs of Portland Beds capped by Purbeck. 1906.
4810	(06, 103) Black Nore Point and neighbouring cliffs, Portland Isle	Cliffs of Portland Beds capped by Purbeck. 1906.
4811	(06, 104) Near Black Nore Point, Portland Isle.	Chert bands in Portland Stone. 1906.
4812	(06, 106) W. side of Portland Isle	Marine erosion of Portland Beds. 1906.
4813	(06, 107) „ „	Talus of Portlandian. 1906.
4814	(06, 108) Black Nore Point, W. side of Portland Isle.	Portland Stone on Portland Sand. 1906.
4815	(06, 109) Black Nore Point, W. side of Portland Isle.	Portland capped by Purbeck, big talus at foot of cliff. 1906.
4816	(06, 110) Portland Bill . . .	Portland Stone. 1906.
4817	(06, 111) „ . . .	„ „
4818	(06, 112) S. of Black Nore Point, Portland.	Stools of trees in Purbeck Beds. 1906.
4819	(06, 114) S. of Black Nore Point, Portland.	„ „ „
4820	(06, 113) Near Easton, Portland .	Contorted Purbeck in railway cutting. 1906.

Regd. No.		
4821	(06, 115) Near Portland Bill . .	Raised Beach on Portland. 1906.
4822	,, ,,	,, ,, ,,
4823	(06, 117) Bran Point, Osmington	Ledges formed of hard bands in the Corallian.
4824	(06, 119) Osmington Mills . .	Corallian section, Sandsfoot Beds above, Trigonia Beds below. 1906.
4825	(06, 120) Bran Point, Osmington	Corallian section, Sandsfoot Beds with Trigonia Beds at foot of cliff. 1906.
4826	(06, 121) Bencliff, near Weymouth	Corallian section, Sandsfoot Grit on Sandsfoot Clay. 1906.
4827	(06, 122) Cliffs N. of Sandsfoot, Weymouth.	Trigonia Beds at foot of cliff. 1906.
4828	(06, 123) Osmington Mills . .	Large dogger in the Bencliff Grits. 1906.
4829	(06, 124) ,, . .	,, ,, ,, ,,
4830	(06, 125) ,, . .	,, ,, ,, ,,
4831	(06, 126) Near Sandsfoot Castle, Weymouth.	Ferruginous concretions in the Sandsfoot Grits (Corallian). 1906.
4832	(06, 127) Near Sandsfoot Castle, Weymouth.	Ferruginous concretions in the Sandsfoot Grits (Corallian). 1906.
4833	(06, 128) Near Sandsfoot Castle, Weymouth.	Ferruginous concretions in the Sandsfoot Grits (Corallian). 1906.
4834	(06, 129) Sandsfoot, near Weymouth.	Branching 'fucoidal bodies' in the Sandsfoot Beds (Corallian). 1906.
4835	(06, 130) Sandsfoot, near Weymouth.	Branching 'fucoidal bodies' in the Sandsfoot Beds (Corallian). 1906.
4836	(06, 131) Sandsfoot, near Weymouth.	Branching 'fucoidal bodies' in the Sandsfoot Beds (Corallian). 1906.
4837	(06, 132) Portland	End of the Chesil Beach. 1906.
4838	(06, 133) Between White Nothe and the Durdle Promontory.	Chalk Cliffs. 1906.
4839	(06, 135) Cliff E. of Holworth House, N.E. of Weymouth.	Chalk resting on Upper Greensand. 1906.
4840	(06, 136) Cliff E. of Holworth House, N.E. of Weymouth.	Chalk resting on Upper Greensand. 1906.
4841	(06, 138) The Durdle Promontory and the neighbouring cliffs.	The Durdle Promontory is Portlandian; the high cliffs to the left are Chalk. 1906.
4842	(06, 140) Near Holworth House, W. of White Nothe.	Unconformable junction of Upper Cretaceous and Upper Jurassic. 1906.
4843	(06, 143) Near Holworth House, W. of White Nothe.	Unconformable junction of Upper Cretaceous and Upper Jurassic. 1906.
4844	(06, 142) Near Holworth House, W. of White Nothe.	Upper Jurassic rocks, Portlandian section to the left, Kimmeridge Clay in right lower half. 1906.

GLOUCESTERSHIRE.—*Photographed by* Miss EILEEN HENDRIKS, *405 Hagley Road, Birmingham.* 1/4.

4845	( ) Dudbridge, nr. Stroud . .	Pit in Middle Lias. 1908.
4846	( ) Breakheart Hill, nr. Nibley	Upper *Trigonia* Grit and Freestone; false bedding. 1908.
4847	( ) Cam Long Down, nr. Nibley	An outlier of the Cotteswolds. 1908.

Photographed by Miss M. S. JOHNSTON, *Hazelwood, Wimbledon.* 1/4.

4848	( ) Leckhampton Hill. . .	Upper *Trigonia* Grit resting on bored surface of Notgrove Freestone. 1908.
4849	( ) Damery Bridge, nr. Tortworth.	Quarry in Trap. 1908.
4850	( ) Damery Bridge, nr. Tortworth.	,,

Photographed by Professor S. H. Reynolds, *M.A., F.G.S., The University, Bristol.* 1/2 *and* 1/4.

Regd. No.		
4851	(05, 21) Avon section, lower cutting on Avonmouth line.	Modiola Beds (Km.). 1905.
4852	(05, 22) Avon section, upper cutting on Avonmouth line.	Bryozoa Bed (hor. α) and Modiola Beds (hor. Km.). 1905.
4853	(05, 23) Avon section, lower cutting on Avonmouth line.	Modiola Beds (Km.). 1905.
4854	(05, 24) Avon section, lower cutting on Avonmouth line.	Bryozoa Bed (hor. α) and Modiola Beds (hor. Km.). 1905.
4855	(05, 25) Avon section, mouth of Durdham Down tunnel.	Passage Beds to O.R.S. 1905.
4856	(05, 26) Avon section, Sea Walls, &c.	Z and K Beds. 1905.
4857	(05, 27) Avon section, general view from the N.	Succession Z_2 to D_1. 1905.
4858	(05, 28) Avon section, Black Rock Quarry and other exposures.	Z Beds with K Beds below. 1905.
4859	(05, 29) Avon section, Black Rock Quarry.	Z Beds and part of C Beds. 1905.
4860	(05, 30) Avon section, Press, and Black Rock Quarries.	Z Beds. 1905.
4861	(99, 31) Avon section, the Gully.	C Beds, Dolomites and Caninia Oolite. 1899.
4862	(05, 31) Avon section, between the Great Quarry and the Gully.	Caninia Dolomites (C_2). 1905.
4863	(05, 32) Avon section, Gully and end of Great Quarry.	Caninia Dolomites and over and underlying strata. 1905.
4864	(05, 33) Avon section, N. ends Great Quarry.	Detail S_1 Beds. 1905.
4865	(05, 34) Avon section, Great Quarry.	S Beds. 1905.
4866	(05, 35) Avon section, Great Quarry.	S Beds and base of D_1. 1905.
4867	(05, 36) Avon section, Clifton .	D Beds between Point Villa and the Great Quarry. 1905.
4868	(05, 38) Avon section, Bridge Valley road, &c.	Succession S_1 to D_2 and the fault. 1905.
4869	(05, 39) Avon section, N. of Observatory Hill, Clifton.	D_2 Beds with S_2 thrust over them. 1905.
4870	(05, 40) Avon section, Observatory Hill and the Suspension Bridge.	S_2 Beds thrust over D_2 Beds. 1905.
4871	(05, 41) Avon section, Clifton Down.	S_2 repeated by the fault. 1905.
4872	(99, 35) Avon section, Observatory Hill.	S_2 Beds thrust over D_2 Beds.
4873	(05, 43) Avon section, between the old zigzag path and the Bridge.	Upper S_2 Beds and lower D_1 Beds repeated by the fault. 1905.
4874	(05, 44) Avon section, Great Quarry to Point Villa.	S and D Beds. 1905.
4875	(05, 45) Avon section, Clifton .	D_1 (and part of D_2) repeated by the fault. 1905.
4876	(06, 154) Shirehampton cutting . .	Syncline of O.R.S. overlain by Dolomitic Conglomerate. 1906.
4877	(08, 1) Brinkmarsh Quarry, Whitfield, near Tortworth.	Wenlock Beds with Limestone bands replaced by Celestine. 1908.
4878	(08, 5) Cullimore's Quarry, Charfield Green.	Ashy Limestone of Silurian age occupying a hollow in Amygdaloidal Basalt. 1908.

Regd. No.		
4879	(06, 165) Garden Cliff on the Severn.	General view, Keuper, Rhætic and base of Lias. 1906.
4880	(06, 166) Garden Cliff on the Severn.	General view, Keuper, Rhætic and base of Lias. 1906.
4881	(06, 167) Garden Cliff on the Severn.	Top of Keuper and base of Rhætic. 1906.
4882	(06, 168) Garden Cliff on the Severn.	Red Keuper Marls forming west end of section. 1906.
4883	(06, 169) Garden Cliff on the Severn.	Lower part of the Rhætic Series. 1906.

HEREFORDSHIRE.—*Photographed by* Professor S. H. REYNOLDS, *M.A., F.G.S., The University, Bristol.* 1/2 *and* 1/4.

4884	(08, 50) Bartestree Quarry . .	Basic dyke in Old Red Sandstone. 1908.
4885	(08, 53) „ „ . .	Junction between Dolerite (left) and altered Old Red Sandstone (right) northern junction. 1908.
4886	(08, 54) „ „ . .	Junction between Dolerite (right) and altered O.R.S. (left) southern junction. 1908.

HERTFORDSHIRE.—*Photographed by* T. W. READER, *F.G.S., 17 Gloucester Road, Finsbury Park, N.* 1/4.

4887	( ) Chadwell Spring, Hertford .	Head of New River Waterworks. 1909.
4888	( ) „ „ .	„ „ „ „

KENT.—*Photographed by* T. W. READER, *F.G.S., 17 Gloucester Road, Finsbury Park, N.* 1/4.

4889	( ) Otford Station . . .	Chalky rainwash. 1909.
4890	( ) „ . . .	„ „
4891	( ) Kemsing	Old chalk quarry, with 'pipes.' 1909.
4892	( ) Green Street Green . .	Gravel pit. 1909.
4893	( ) „ . .	„ „
4894	( ) „ . .	„ „

SHROPSHIRE.—*Photographed by* GODFREY BINGLEY, *Thorniehurst, Headingley, Leeds.* 1/2.

4895	(8064) Selattyn	Carboniferous Limestone with *Lithostrotion irregulare.* 1908.

SOMERSET.—*Photographed by* JAMES PARKER, *M.A., F.G.S., 21 Turl Street, Oxford.* 1/4.

4896	(8) Doulting	Quarry in Doulting Stone, Inferior Oolite. 1909.
4897	(7) Waterlip Quarry, nr. Frome .	Carboniferous Limestone, β, Z_1, Z_2. 1909.
4898	(3) Vallis Vale	Inferior Oolite resting unconformably on Carboniferous Limestone. 1909.
4899	(2) „	Inferior Oolite resting unconformably on Carboniferous Limestone. 1909.
4900	(1) „	Inferior Oolite resting unconformably on Carboniferous Limestone. 1909.

Photographed by R. Vowell Sherring, *F.G.S., Hallatrow, nr. Bristol.* 10/8.

Regd. No.		
4901	(1) Sunnyhill Quarry, nr. Stoke Lane.	Tuff and Andesite. 1907.
4902	(2) Sunnyhill Quarry, nr. Stoke Lane.	,, ,, ,,
4903	(3) Moon Hill, nr. Stoke Lane .	Vent; ashy Conglomerate. 1907.
4904	(3*a*) ,, ,, .	,, ,, ,,
4905	(4) Beacon Hill, from Moon Hill .	1907.
4906	(A) Spring Cove, nr. Weston-super-Mare.	Carboniferous Agglomerate. 1907.
4907	(B) Spring Cove, nr. Weston-super-Mare.	Carboniferous Limestone and volcanic rocks. 1907.
4908	(C) Middle Hope Bay, nr. Woodspring Priory.	Carboniferous Limestone, ashy. 1907.
4909	(E) Middle Hope Bay, nr. Woodspring Priory.	,, ,, ,, ,,
4910	(D) Middle Hope Bay, nr. Woodspring Priory.	Limestone with *Zaphrentis* and volcanic ash. 1907.
4911	(F) Middle Hope Bay, nr. Woodspring Priory.	Massive Limestone with lapilli in lower part. 1907.

Photographed by Professor S. H. Reynolds, *M.A., F.G.S., The University, Bristol.* 1/2 *and* 1/4.

4912	(05, 17) Worle Hill. . . .	Carboniferous; folded S Beds. 1905.
4913	(05, 47) Avon section, Leigh Woods.	Quarry 1 and 2 with the succession from Z_1 to C_1. 1905.
4914	(05, 48) Avon section, Leigh Woods.	Quarry 1, 2 and 3 with the succession from Z_1 to C_2.
4915	(05, 49) Avon section, Leigh Woods.	Quarry 4 and 5 with the S_2 and lower D_1 Beds. 1905.
4916	(05, 50) Avon section, Leigh Woods.	Quarry 2 and 3 with the succession from Z_2 to C_2. 1905.
4917	(05, 52) Avon section, Leigh Woods.	Quarry 5 with S_2 Beds and base of D_1. 1905.
4918	(05, 53) Avon section, Leigh Woods.	Quarry 5 with upper S_2 and lower D_1 Beds. 1905.
4919	(05, 59) Source of Axe, Wookey Cave.	1905.
4920	(06, 147) The Ebbor Gorge, Mendips.	Gorge in Carboniferous Limestone. 1906.
4921	(06, 149) O.R.S. of Woodhill Bay, Portishead.	Shales on massive Sandstone. 1906.
4922	(06, 151) O.R.S. of Woodhill Bay, Portishead.	Limestone and Conglomerate. 1906.
4923	(06, 152) O.R.S. of Woodhill Bay, Portishead.	Conglomeratic layer overlying Calcareous layer. 1906.
4924	(06, 157) S.E. of Moon's Hill, Stoke Lane, Mendips.	Quarry in coarse ashy Conglomerate. 1906.
4925	(06, 159) S.E. of Moon's Hill, Stoke Lane, Mendips.	Quarry in coarse ashy Conglomerate. 1906.
4926	(07, 62) Woodspring or Swallow Cliff (Middle Hope).	Raised Beach. 1907.
4927	(07, 64) Woodspring or Swallow Cliff (Middl[illegible]	Spheroidal Basalt resting on Tuff veined with Calcite. 1907.
4928	(07, 64*) Wo[illegible]allow Cliff (Mi[illegible]	Bedded Tuff on Amygdaloidal Basalt. 1907.
4929	(07, 65) W[illegible] Cli[illegible]	Vesicular lapilli in Limestone. 1907.

Regd. No.		
4930	(07, 66) Woodspring or Swallow Cliff (Middle Hope).	Vesicular lapilli in Limestone. 1907.
4931	(07, 67) Spring Cove, Weston-super-Mare.	Basalt enclosing Limestone masses. 1907.
4932	(07, 68) Spring Cove, Weston-super-Mare.	Basalt and Limestone enclosed in Tuff. 1907.
4933	(07, 70) Spring Cove, Weston-super-Mare.	Basalt enclosing Limestone masses. 1907.
4934	(07, 71) Spring Cove, Weston-super-Mare.	Calcareous bands between Basalt spheroids. 1907.
4935	(07, 74) Spring Cove, Weston-super-Mare.	Spheroids of Basalt in Tuff. 1907.
4936	(07, 75) Spring Cove, Weston-super-Mare.	,, ,, ,, ,, ,,
4937	(07, 76) Spring Cove, Weston-super-Mare.	,, ,, ,, ,, ,,
4938	(07, 77) Spring Cove, Weston-super-Mare.	Lava enclosing Limestone mass. 1907.
4939	(08, 10) Western end of Mendip range, Uphill, Brean and Steep Holmes.	1908.
4940	(08, 11) Brean Down . . .	Southern (scarp) face. 1908.
4941	(08, 12) Western end of Mendip range from Brean Down.	1908.
4942	(08, 13) Brean Down . . .	Northern (dip slope) face. 1908.

STAFFORDSHIRE.—*Photographed by* A. H. BASSANO, *Hadenholme, Old Hill, Staffs.* 1/2.

4943	( ) Darby's Hill Quarry, Rowley Regis.	Columnar Dolerite. 1909.
4944	( ) New Turner's Hill Quarry, Rowley Regis.	Weathered spheroidal Dolerite. 1909.

SURREY.—*Photographed by* J. H. BALDOCK, *F.R.P.S., Overdale, St. Leonards Road, Croydon.* 1/2.

4945	(08, 307) Worms Heath, nr. Upper Warlingham.	Funnel-shaped mass on Chalk in Gravel. 1908.
4946	(08, 308) Worms Heath, nr. Upper Warlingham.	Gravel pit. 1908.
4947	(08, 309) Worms Heath, nr. Upper Warlingham.	,, ,,
4948	(08, 310) Worms Heath, nr. Upper Warlingham.	,, ,,

Photographed by T. W. READER, *F.G.S.*, 17 *Gloucester Road, Finsbury Park, N.* 1/4.

4949	( ) Monkshatch, nr. Guildford .	Chalk; zones of *M. cor-testudinaria*, *H. planus*, and *T. gracilis*. 1909.
4950	( ) ,, ,, .	Chalk; zones of *M. cor-testudinaria*, *H. planus*, and *T. gracilis*. 1909.

SUSSEX.—*Photographed by* T. W. READER, *F.G.S.*, 17 *Gloucester Road, Finsbury Park, N.* 1/4.

4951	( ) Rottingdean Cliffs . . .	Chalk; zone of *A. quadratus*. 1909.
4952	( ) ,, ...	,, ,, ,,
4953	( ) ,, ...	,, ,, ,,
4954	( ) ,, . . .	,, ,, ,,
4955	( ) ,, . .	,, ,, ,,
4956	( ) ,, .	,, ,, ,,

Photographed by J. T. RODDA, *Eastbourne.* 1/2.

Regd. No.			
4957	( )	Cuckmere Haven . . .	Paramoudra on beach. 1907.
4958	( )	„ . . .	Mass of Flint. 1907.

YORKSHIRE.—*Photographed by* GODFREY BINGLEY, *Thorniehurst, Headingley, Leeds.* 1/2.

4959	(8332)	Barton Quarry, nr. Richmond.	Crinoidal Limestone (underset Limestone), Yoredale Series. 1908.
4960	(8333)	Barton Quarry, nr. Richmond.	Crinoidal Limestone (underset Limestone), Yoredale Series. 1908.
4961	(8334)	Barton Quarry, nr. Richmond.	Boulder Clay resting on underset Limestone. 1908.
4962	(8335)	Barton Quarry, nr. Richmond.	Boulder Clay resting on underset Limestone. 1908.
4963	(8336)	Barton Quarry, nr. Richmond.	Glaciated surface of underset Limestone and overlying Boulder Clay. 1908.
4964	(8337)	Barton Quarry, nr. Richmond.	Glaciated surface of underset Limestone. 1908.
4965	(8338)	Barton Quarry, nr. Richmond.	Underset Limestone (Yoredale Series). 1908.
4966	(8339)	Barton Quarry, nr. Richmond.	Boulder Clay. 1908.
4967	(8340)	Barton Quarry, nr. Richmond.	Boulder Clay filling joints in Cherty Limestone. 1908.
4968	(8341)	Barton Quarry, nr. Richmond.	Chert in underset Limestone. 1908.
4969	(8342)	Barton Quarry, nr. Richmond.	Cherts and Crinoids in underset Limestone. 1908.
4970	(8343)	Barton Quarry, nr. Richmond.	Wedge-bedded Yoredale Limestone. 1908.
4971	(8344)	Forcett Quarry, nr. Richmond.	Pre-glacial floor of Yoredale Limestone. 1908.
4972	(8345)	Forcett Quarry, nr. Richmond.	Quarry in 'Main Limestone' (Yoredale Series). 1908.
4973	(8346)	Forcett Quarry, nr. Richmond.	Drift-filled cavity in Limestone floor. 1908.
4974	(7953)	The Needle's Eye, Newtondale, nr. Pickering.	Kellaway Rock. 1907.
4975	(7954)	Near the Needle's Eye, Newtondale, nr. Pickering.	Kellaway Rock escarpment. 1907.
4976	(7957)	Staindale	The 'Bridestones' seen on the left. 1907.
4977	(7958)	The Bridestones, nr. Pickering.	Weathered Calcareous Grit. 1907.
4978	(7959)	The Bridestones, nr. Pickering.	„ „ „
4979	(7960)	The Bridestones, nr. Pickering.	Undercut Calcareous Grit. 1907.
4980	(7962)	The Bridestones, nr. Pickering.	„ „ „
4981	(7570)	Cliffs N. of Robin Hood's Bay.	Lias. 1907.
4982	(7573)	Cliffs N. of Robin Hood's Bay.	„ „
4983	(7576)	Cliffs, Robin Hood's Bay .	Lower Lias. 1907.
4984	(7580)	Peak .	Dogger with bands of pebbles and shells weathered out. 1907.
4985	(7583)	Blea[illegible]	Impression of iron plate from wreck on boulder, caused by action of waves.

Regd. No.		
4986	(7584) Blea Wyke	Impression of iron plate from wreck on boulder, caused by action of waves. 1907.
4987	(7586) ,, ...	Boulders on shore, worn and dovetailed into one another by action of waves. 1907.
4988	(7587) ,, ...	Boulders on shore, worn and dovetailed into one another by action of waves. 1907.
4989	(7588) ,, ...	*Nerinea* Bed in Dogger. 1907.
4990	(7591) Hawsker Bottom . .	Current bedding in block of Dogger. 1907.
4991	(7592) ,, . .	Upper Lias Breccia. 1907.
4992	(7593) ,, . .	Current bedding in block of Dogger. 1907.
4993	(7594) ,, . .	Block of Dogger with pebbles. 1907.
4994	(7596) ,, . .	Upper Lias Breccia. 1907.
4995	(7598) Near Castle Chamber, Hawsker Bottom.	Spinatus zone. 1907.
4996	(7599) Castle Chamber, Hawsker Bottom.	
4997	(7600) Cliffs, Hawsker Bottom .	Estuarine Beds, Dogger and Upper Lias. 1907.
4998	(7602) ,, ,, ,, .	Estuarine Beds, Dogger and Upper Lias. 1907.
4999	(7604) Hawsker Bottom . .	Marine pot-hole. 1907.
5000	(7606) Robin Hood's Bay . .	Block of Middle Lias full of Pecten, &c. 1907.
5001	(7608) ,, ,, .	Block of Middle Lias with *Dentalium giganteum.* 1907.
5002	(7610) Peak Alum Quarries . .	Dogger and Upper Lias. 1907.
5003	(7613) ,, ,, . .	,, ,, ,,
5004	(7614) ,, ,, . .	,, ,, ,,
5005	(7618) ,, ,, . .	,, ,, ,,
5006	(8372) Marske Quarry, nr. Saltburn.	Lower Estuarine Sandstones with Plant Beds. 1908.
5007	(8379) Marske Quarry, nr. Saltburn.	Blocks of Lower Estuarine Sandstone with fossil Plants. 1908.
5008	(8380) Marske Quarry, nr. Saltburn.	Blocks of Lower Estuarine Sandstone with fossil plants. 1908.
5009	(8383) Shore under Huntcliff S. of Saltburn.	'Mushroom rocks'—undercut Middle Lias blocks. 1908.
5010	(8384) Shore under Huntcliff S. of Saltburn.	'Mushroom rock' and pot-hole. 1908.
5011	(8385) Shore under Huntcliff S. of Saltburn.	'Mushroom rocks'—undercut Middle Lias blocks. 1908.
5012	(8386) Shore under Huntcliff S. of Saltburn.	'Mushroom rocks'—undercut Middle Lias blocks. 1908.
5013	(8388) Shore under Huntcliff S. of Saltburn.	Boulders of Middle Lias on Lower Lias floor. 1908.
5014	(8390) Shore under Huntcliff S. of Saltburn.	'Mushroom rocks'—undercut Middle Lias blocks. 1908.
5015	(8391) Huntcliff and shore at low water.	'Mushroom rocks' on Lower Lias Shales. 1908.
5016	(8393) Cliffs N. of Skinningrove .	Middle Lias. 1908.
5017	(8394) Cat Nab, Saltburn . .	Hill of Boulder Clay isolated by stream action. 1908.
5018	(7426) Headingley, Leeds . .	Cutting in Boulder Clay. 1907.
5019	(7427) ,, ,,	,,
5020	(7428) ,, ,, . .	B[illegible] Boulders. 1907.
5021	(7430) ,, ,, .	[illegible] Clay. 1907.
5022	(7431) ,, ,,	[illegible] 1907.

Regd. No.		
5023	(8034) Hawkesworth Quarry, Horsforth, nr. Leeds.	Channel in Millstone Grit filled with Coal Measure Shales. 1908.
5024	(8035) Hawkesworth Quarry, Horsforth, nr. Leeds.	Coal Measure Shales on Millstone Grit. 1908.
5025	(8036) Hawkesworth Quarry, Horsforth, nr. Leeds.	Sandstone band near base of Coal Measures. 1908.
5026	(8038) Hawkesworth Quarry, Horsforth, nr. Leeds.	Sloping surface of Millstone Grit. 1908.
5027	(8039) Hawkesworth Quarry, Horsforth, nr. Leeds.	Coal Measure Shales with thin Coal seam. 1908.

Photographed by Professor S. H. REYNOLDS, *M.A.*, *F.G.S.*, *The University*, *Bristol.* 1/4.

5028	(06, 171) By the Nidd below Knaresborough.	Unconformity, Magnesian Limestone on Millstone Grit. 1906.
5029	(06, 176) Knaresborough . .	The Dropping Well. 1906.
5030	(06, 177) ,, . .	Petrification in progress at the Dropping Well. 1906.

WALES.

CARNARVON.—*Photographed by* Professor S. H. REYNOLDS, *M.A.*, *F.G.S.*, *The University*, *Bristol.* 1/4.

5031	(06, 88) Carn Boduan, nr. Nevin.	Formed by an 'Andesitic intrusion.' 1906.
5032	(06, 92) Careg-y-defaid, Pwllheli.	Weathered surface of nodular Rhyolite. 1906.
5033	(06, 93) ,, ,, .	Weathered surface of nodular Rhyolite. 1906.
5034	(06, 94) ,, ,, .	Weathered surface of nodular Rhyolite. 1906.
5035	(06, 95) ,, ,, .	Weathered surface of nodular Rhyolite. 1906.
5036	(06, 96) ,, ,, .	Weathered surface of nodular Rhyolite. 1906.
5037	(06, 97) ,, ,, .	Weathered surface of nodular Rhyolite. 1906.
5038	(06, 98) Pen-y-chain, Pwllheli .	Weathered surface of banded Rhyolite. 1906.
5039	(06, 99) ,, ,, .	Weathered surface of nodular Rhyolite. 1906.

DENBIGH.—*Photographed by* GODFREY BINGLEY, *Thorniehurst*, *Headingley*, *Leeds.* 1/2 *and* 1/4.

5040	(8066) Cae Deicws, Llansaintffraid, Glyn Ceiriog.	Intrusive columnar Felsite. 1908.
5041	(8067) Llansaintffraid, Glyn Ceiriog.	Quarry in Rhyolite. 1908.
5042	(8069) Castle Mill Quarry, Glyn Ceiriog.	Carboniferous Limestone. 1908.
5043	(8072) Eglwyseg Rocks, Llangollen.	Carboniferous Limestone escarpment. 1908.
5044	(8074) Trevor Quarry, Eglwyseg, Llangollen.	Carboniferous Limestone. 1908.
5045	(8076) Trevor Quarry, Eglwyseg, Llangollen.	Lode in Carboniferous Limestone. 1908.
5046	(8094) Cader B[illegible] from above Pistyll R[illegible]	
5047	(8097) Ll[illegible] Mo[illegible]	

MERIONETH.—*Photographed by* Professor S. H. REYNOLDS, *M.A.*, *F.G.S.*, *The University*, *Bristol.* 1/4.

Regd. No.		
5048	(06, 90) Cwm Bychan, nr. Harlech	Harlech Grits. 1906.

MONTGOMERY.—*Photographed by* GODFREY BINGLEY, *Thornichurst*, *Headingley*, *Leeds.* 1/4.

5049	(8106) Llangynog	Upper portion of volcanic neck. 1908.
5050	(8109) Pennant Valley, Llangynog	1908.
5051	(8110) Llangynog	Lower portion of volcanic neck. 1908.
5052	(8117) "	Volcanic neck. 1908.

PEMBROKE.—*Photographed by* Professor S. H. REYNOLDS, *M.A.*, *F.G.S.*, *The University*, *Bristol.* 1/4.

5053	(05, 71) Coast S.E. of Nun's Chapel, St. Davids.	Cambrian Sandstone and Basal Conglomerate, also Pebidian. 1905.
5054	(05, 73) Nun's Chapel, St. Davids	Weathered surface of Basal Conglomerate of Cambrian. 1905.
5055	(09, 1) Old Castle Head, Tenby .	Gullies eroded along Shale bands in vertical O.R.S. 1909.
5056	(09, 2) " " .	Gullies eroded along Shale bands in vertical O.R.S. 1909.
5057	(09, 3) Skrinkle Haven, Tenby .	Top of O.R.S. (left) and base of Carboniferous (right). 1909.
5058	(09, 4) " " .	Arch eroded along bedding planes of vertical Carboniferous Limestone. 1909.
5059	(09, 5) Old Castle Head, Tenby .	Cracks in 'race' beds. 1909.
5060	(09, 6) W. of Lydstep, Tenby .	Gash-Breccia and sea cave. 1909.
5061	(09, 7) Stackpole Quay, Tenby .	Anticline in Carboniferous Limestone (hor. C.). 1909.
5062	(09, 8) Wreckfield Quarry, Tenby	Limestone full of *Productus giganteus.* 1909.
5063	(09, 10) Bullslaughter Bay, Stack Rocks.	Gash-Breccia. 1909.
5064	(09, 11) Near Bullslaughter Bay, Stack Rocks.	Chert in Carboniferous Limestone. 1909.
5065	(09, 12) Near Bullslaughter Bay, Stack Rocks.	" " " "
5066	(09, 14) Stack Rocks, W. of Tenby	Marine erosion of Carboniferous Limestone. 1909.
5067	(09, 18) " "	Marine erosion of Carboniferous Limestone. 1909.
5068	(09, 19) Skrinkle Haven, Tenby .	Sea caves. 1909.
5069	(09, 20) Near Skrinkle Haven, Tenby.	Erosion along bedding planes of vertical Carboniferous Limestone. 1909.
5070	(09, 21) Cliffs, N. side of Skrinkle Haven, Tenby.	Vertical Carboniferous Limestone. 1909.

RADNOR.—*Photographed by* Professor S. H. REYNOLDS, *M.A.*, *F.G.S.*, *The University*, *Bristol.* 1/4.

5071	(05, 65) Caban Coch, Rhyader .	Llandovery Conglomerate. 1905.
5072	(05, 66) " " .	Cleaved Slate band in Llandovery Conglomerate. 1905.
5073	(05, 67) " "	Section of Llandovery. 1905.
5074	(05, 69) Pont Hyllfan, Elan Valley, Rhyader.	Pot-holes. [illegible]05.
5075	(05, 70) Pont Hyllfan, Elan Valley Rhyader.	

ISLE OF MAN.

Photographed by GODFREY BINGLEY, *Thorniehurst, Headingley, Leeds.* 1/2 *and* 1/4.

Regd. No.		
5076	(7716) The Whing, Port Soderick	Folds in Lonan Flags. 1907.
5077	(7718) " "	" " "
5078	(7628) Ronaldsway, Derby Haven	1907.
5079	(7629) " "	Basement Conglomerate of Carboniferous faulted against Carboniferous Limestone. 1907.
5080	(7630) " "	'Knobby' surface of Lower Carboniferous Limestone. 1907.
5081	(7631) St. Michael's Island, Langness.	Stratification crossed by cleavage in Manx Slates. 1907.
5082	(7635) The Arches, Langness .	Carboniferous Basement Conglomerate resting unconformably on Manx Slates. 1907.
5083	(7636) " " .	Joint plane cutting pebbles of Carboniferous Basement Conglomerate. 1907.
5084	(7637) " " .	Fault in Carboniferous Basement Conglomerate. 1907.
5085	(7638) Shore opposite Scarlet Quarry.	Lower Carboniferous Limestone containing Campophyllum. 1907.
5086	(7639) Shore near Scarlet Quarry	Lithostrotion mass in Carboniferous Limestone. 1907.
5087	(7641) Scarlet	Undulations in Carboniferous Limestone. the Stack of Scarlet in the distance 1907.
5088	(7643) Scarlet Point . . .	Carboniferous volcanic rocks. 1907.
5089	(7644) " . . .	Stack of Scarlet with Agglomerate in the foreground. 1907.
5090	(7645) " . . .	Ropy Lava. 1907.
5091	(7646) Near Scarlet Point . .	Undulations in Carboniferous Limestone. 1907.
	(7647) " " . .	Undulations in Carboniferous Limestone. 1907.
5092	(7650) Scarlet Point . . .	Disturbed Carboniferous Limestone containing quartz pebbles. 1907.
5093	(7651) " . . .	Junction of Flaggy Carboniferous Limestone with Volcanic Series. 1907.
5094	(7652) Cromwell's Walk, Scarlet Point.	Jointing and flow structure in Carboniferous Lava. 1907.
5095	(7653) Cromwell's Walk, Scarlet Point.	Jagged edge to jointed Carboniferous Lava. 1907.
5096	(7654) Near Scarlet Point . .	Sea-worn gullies along joints in Carboniferous ash. 1907.
5097	(7655) 250 yards S. of Close ny Chollagh Point.	Overthrust in bedded volcanic ash. 1907.
5098	(7656) 250 yards S. of Close ny Chollagh Point.	Overthrust in bedded volcanic ash. 1907.
5099	(7657) Close ny Chollagh Point .	Crumpling of band of Carboniferous Limestone. 1907.
5100	(7660) Poyll Vaaish . . .	Dome of Carboniferous Limestone. 1907.
5101	(7661) "	'Reef knolls' surrounded by Flaggy Limestone. 1907.
5102	(7662) " [illegible] .	'Reef knolls' surrounded by Flaggy Limestone. 1907.
5103	(7663) [illegible]	Dome of Flaggy and underlying 'Reef knoll' Limestone. 1907.
5104	(7664) [illegible]	[illegible] knoll' Limestone. 1907.

Regd. No.		
5105	(7685) Gob-y-Strona, Maughold Head.	Contorted Manx Slates. 1907.
5106	(7690) Gob-y-Deigan . . .	Cave in Crush Conglomerate in Manx Slates. 1907.
5107	(7692) Between Gob-y-Deigan and Gob-y-Skeddan.	Manx Slates reduced to Crush Conglomerate. 1907.
5108	(7693) Between Gob-y-Deigan and Gob-y-Skeddan.	Manx Slates reduced to Crush Conglomerate. 1907.
5109	(7694) Between Gob-y-Deigan and Gob-y-Skeddan.	Manx Slates reduced to Crush Conglomerate. 1907.
5110	(7695) Between Gob-y-Deigan and Gob-y-Skeddan.	Sea cave in Crush Conglomerate. 1907.
5111	(7697) Between Gob-y-Deigan and Gob-y-Skeddan.	Sea caves in Crush Conglomerate. 1907.
5112	(7707) Baroo Ned, Spanish Head.	Quartz veining in Manx Slates. 1907.
5113	(7708) Baroo Ned, Spanish Head.	Cliff section of disturbed Manx Slates.
5114	(7711) Bay Stacka and Sugarloaf seen from Spanish Head.	Flaggy Grits in Manx Slates, probably overfolded. 1907.
5115	(7713) Bay Stacka and Sugarloaf from Spanish Head.	Flaggy Grits in Manx Slates. 1907.
5116	(7719) The Whing, Port Soderick	Fold in Lonan Flags. 1907.

SCOTLAND.

ARGYLLSHIRE.—*Photographed by* RUSSELL F. GWINNELL, *B.Sc., F.G.S., 33 St. Peter's Square, W.* 1/4.

5117	(74) Eilean nan Gamha, Lismore	Glaciated rock surface. 1907.
5118	(75) Near Balnagawan Mill, Lismore.	Raised beach and inclined sill of Basalt. 1907.
5119	(78) Near Balnagawan Mill, Lismore.	Terrace of Travertine. 1907.

Photographed by A. E. V. ZEALLEY, *B.Sc., A.R.C.S., Rhodesia Museum, Bulawayo.* 1/4.

5120	(113) Glen Croe, Loch Long. .	Delta. 1907.

AYR.—*Photographed by* Professor S. H. REYNOLDS, *M.A., F.G.S., The University, Bristol.* 1/4.

5121	(08, 18) Ardmillan Shore S. of Girvan.	Marine erosion of Whitehouse Beds. 1908.
5122	(08, 19) Ardmillan Shore S. of Girvan.	Marine erosion of Whitehouse Beds. 1908.
5123	(08, 21) N. of Kennedy's Pass, S. of Girvan.	Contorted Ardwell Beds. 1908.
5124	(08, 22) N. of Kennedy's Pass, S. of Girvan.	,, ,, ,,
5125	(08, 24) Stockinray Shore, S. of Girvan.	Arenig Agglomerate. 1908.
5126	(08, 25) Stockinray Shore, S. of Girvan.	,,
5127	(08, 28) Near Bennane Cave, S. Girvan.	,,

Regd. No.		
5128	(08, 29) Bennane Head, S. of Girvan.	Red Chert bands interbedded in Arenig Lava. 1908.
5129	(08, 31) S. of Downan Point, Ballantrae.	Red Chert bands interbedded in Arenig Lava. 1908.
5130	(08, 32) Near Bennane Cave, S. of Girvan.	Contorted Arenig Radiolarian Cherts. 1908.
5131	(08, 35) Downan Point, Ballantrae	Pillow Lava. 1908.
5132	(08, 37) Balcreuchan Port, S. of Girvan.	" "
5133	(08, 38) S. of Downan Point, Ballantrae.	" "
5134	(08, 42) Burnfoot, Shore S. of Girvan.	Raised shore platform. 1908.
5135	(08, 44) Bennane Head, S. of Girvan.	Raised sea cave. 1908.
5136	(08, 48) Kennedy's Pass, S. of Girvan.	Benan Conglomerate. 1908.

DUMBARTONSHIRE.—*Photographed by* A. E. V. ZEALLEY, *B.Sc., A.R.C.S., Rhodesia Museum, Bulawayo.* 1/4.

5137	(109) Loch Lomond . . .	From shore above Ardlui. 1907.
5138	(110) " . . .	Glaciated islands. 1907.
5139	(111) N.E. of Loch Garabal, near Ardlui.	Glaciated surface and erratics. 1907.
5140	(125) Dumbarton Castle Rock .	Jointing. 1907.

EDINBURGH.—*Photographed by* Professor S. H. REYNOLDS, *M.A., F.G.S., The University, Bristol.* 1/4.

5141	(06, 17) Salisbury Crags, from the S.	Shows the underlying Old Red Sandstone. 1906.
5142	(06, 18) Salisbury Crags . .	Shows the Old Red Sandstone below the Dolerite. 1906.
5143	(06, 21) " . .	Junction of intrusive Dolerite and Old Red Sandstone. 1906.
5144	(06, 22) The Dasses, Arthur's Seat	1906.
5145	(06, 25) Queen's Drive, Arthur's Seat.	Agglomerate of vent. 1906.
5146	(06, 26) Arthur's Seat . . .	Agglomerate of 'Gutted Haddie.' 1906.
5147	(06, 28) Salisbury Crags, Arthur's Seat.	Spheroidal weathering of Dolerite. 1906.

INVERNESS—SKYE.—*Photographed by* Professor S. H. REYNOLDS, *M.A., F.G.S., The University, Bristol.* 1/4.

5148	(07, 3) Glamaig and Beinn Dearg, Skye.	Two of the Red Hills. 1907.
5149	(07, 6) Beinn na Caillich, Skye .	One of the Red Hills, Agglomerate of the Kilchrist neck in the foreground. 1907.
5150	(07, 10) Slopes of Cuillins, N. of Ufhart Point, Skye.	Gabbro veins in Peridotite. 1907.
5151	(07, 11) An Sguman, S.E. of Glen Brittle, Skye.	Jointing in Peridotite. 1907.
5152	(07, 12) An Sguman, S.E. of Glen Brittle, Skye.	Pitted weathering of Peridotite. 1907.
5153	(07, 17) Slopes of Cuillins, S.E. of Glen Brittle, Skye.	Glaciation. 1907.
5154	(07, 19) Slopes of Cuillins, S.E. of Glen [illegible]	" "

Regd. No.		
5155	(07, 21) N.E. shore of Loch Brittle, Skye.	Basalt dyke in bedded Basalts. 1907.
5156	(07, 22) Sgurr Brittle, Skye . .	Cascade over bedded Basalts and intrusive sheets of Dolerite. 1907.
5157	(07, 24) N.E. shore of Loch Brittle, Skye.	Agglomerate (?) of a small vent. 1907.
5158	(07, 25) Head of Loch Brittle, Skye.	Small Basalt dyke in bedded Basalts. 1907.
5159	(07, 26) Near head of Loch Brittle.	Vesicular Basalt. 1907.
5160	(07, 27) S. end of Beinn Suardal, nr. Broadford, Skye.	Dyke in Cambrian Limestone. 1907.
5161	(07, 29) Torran, S.W. of Broadford, Skye.	Juxtaposed dykes, 1907.
5162	(07, 30) Torran, S.W. of Broadford, Skye.	,, ,,
5163	(07, 32) Near S. end of Beinn Suardal, nr. Broadford, Skye.	'Grikes' in Cambrian Limestone. 1907.
5164	(07, 34) Shore W. of Broadford, Skye.	Sill in Lias. 1907.
5165	(07, 35) Shore W. of Broadford, Skye.	Gully formed by weathering of dyke in Lias. 1907.
5166	(07, 36) Shore W. of Broadford, Skye.	Basalt sheet resting on Felsite. 1907.
5167	(07, 37) Shore W. of Broadford, Skye.	Gully formed by weathering of dyke in Lias. 1907.
5168	(07, 38) Shore W. of Broadford, Skye.	Intersecting dykes in Lias. 1907.
5169	(07, 39) Shore W. of Broadford, Skye.	Small dyke in Lias. 1907.
5170	(07, 43) Glenbrittle House, Skye .	Fluviatile Conglomerate. 1907.
5171	(07, 44) ,, ,, .	,, ,, ,,
5172	(07, 45) ,, ,, .	,, ,, ,,
5173	(07, 46) ,, ,, .	,, ,, ,,
5174	(07, 47) N. of Boreraig, Skye .	Triassic Breccia. 1907.
5175	(07, 48) ,, ,, .	,, ,,
5176	(07, 49) S. of Beinn Suardal, nr. Broadford, Skye.	Sink holes in Cambrian Limestone. 1907.
5177	(07, 50) S. of Beinn Suardal, nr. Broadford, Skye.	,, ,, ,, ,,
5178	(07, 52) Shore at Boreraig, S. of Broadford, Skye.	Lower Lias Shales. 1907.
5179	(07, 53) Rudh'an Eireannaich, N.W. of Broadford, Skye.	Composite sill. 1907.
5180	(07, 54) S.E. of Loch Kilchrist, S.W. of Broadford, Skye.	Large multiple dyke. 1907.
5181	(07, 55) S.W. of Loch Kilchrist, S.W. of Broadford, Skye.	,, ,, ,,

DUBLIN.—*Photographed by* Professor S. H. REYNOLDS, *M.A., F.G.S., The University, Bristol.* 1/4.

5182	(06, 197) Killiney Shore . .	Granite dykes in Mica Schist. 1906
5183	(06, 198) ,, . .	Granite dyke in Mica Schist. 1906.
5184	(06, 200) ,, . .	Intrusive junction, Granite and Mica Schist. 1906.
5185	(06, 202) ,, . .	Intrusive junction, Granite and Mica Schist. 1906.

5186	(06, 203) Killiney Shore . .	Weathered surface of Andalusite Schist. 1906.
5187	(06, 190) S. of Glensaul . .	Limestone Breccia. 1906.
5188	(06, 193) Glensaul (N. of the School).	Coarse Arenig Tuff. 1906.
5189	(06, 194) Glensaul (N. of the School).	" " "

GALWAY.—*Photographed by* Professor S. H. REYNOLDS, *M.A., F.G.S., The University, Bristol.* 1/4.

Regd. No.		
5190	(06, 195) Glensaul (N. of the School).	Coarse Arenig Tuff. 1906.
5191	(06, 196) Glensaul (N. of the School).	" " "
5192	(09, 23) E. of top of Lettereeneen Hill.	Ice-worn mass of coarse Arenig Breccia. 1909.
5193	(09, 26) N. of Lettereeneen Village, Glensaul.	Coarse Arenig Conglomerate. 1909.
5194	(09, 28) Glensaul	Highly disturbed Tuffs and Radiolarian Cherts. 1909.
5195	(09, 29) "	Highly disturbed Tuffs and Radiolarian Cherts. 1909.
5196	(09, 30) "	Highly disturbed Tuffs and Radiolarian Cherts. 1909.
5197	(09, 32) "	Thick mass of Arenig Chert. 1909.
5198	(09, 34) The Partry Mountains from Lettereeneen.	A dissected plateau, sending spurs northwards. 1909.
5199	(09, 35) The Partry Mountains, from Lettereeneen.	A dissected plateau, sending spurs northwards. 1909.

MAYO.—*Photographed by* Professor S. H. REYNOLDS, *M.A., F.G.S., The University, Bristol.* 1/4.

5200	(07, 78) Near Shangort, Tourmakeady.	Massive Limestone of Arenig age. 1907.
5201	(07, 79) Near Gortbunacullin, Tourmakeady.	Limestone Breccia, 1907.
5202	(07, 82) W. of Gortbunacullin Farm Bridge, Tourmakeady.	" "
5203	(07, 83) S.W. of Gortbunacullin, Tourmakeady.	" "
5204	(07, 84) S. of Gortbunacullin, Tourmakeady.	Banded Felsite. 1907.
5205	(07, 89) Near Ballinrobe . .	Chert masses in Carboniferous Limestone. 1907.
5206	(07, 90) " . .	'Grikes' in Carboniferous Limestone. 1907.
5207	(07, 91) " . .	Cavities of solution in Carboniferous Limestone. 1907.
5208	(07; 92) " . .	Cavities of solution in Carboniferous Limestone. 1907.
5209	(07, 93) " . .	Carboniferous Limestone country. 1907.
5210	(07, 99) W. of Ballinrobe . .	Syringopora Limestone. 1907.

Topographical and Geological Terms used locally in South Africa.—Report of the Committee, consisting of Mr. G. W. LAMPLUGH *(Chairman)*, Dr. F. H. HATCH *(Secretary)*, Dr. G. CORSTORPHINE, *and* Messrs. A. DU TOIT, A. P. HALL, G. KYNASTON, F. P. MENNELL, *and* A. R. ROGERS, *appointed to determine the precise Significance of Topographical and Geological Terms used locally in South Africa. (Drawn up by the Secretary.)*

DURING the year Messrs. Rogers and du Toit have sent in some corrections, and Mr. du Toit has contributed a few fresh words. These have been embodied in the present Report.

Two classes of words are at present being catalogued:—

I. Topographical terms.
II. Names of rocks and minerals.

Most of the words hitherto catalogued are of Dutch origin, but some Kaffir and Bushman words have also been included.

CLASS I.—*Topographical Terms.*

Aar—

Is the name given to any feature on the surface which is very long compared with its breadth. Applied to the outcrop of a dyke, to a low ridge of tufa, to a slight depression, or most frequently to a line of country characterised by a particular kind of bush.

Baai—

A bay on the coast, *e.g.*, Saldanha Baai.

Bak—

A basin or basin-shaped hollow.

Bank—

A low ridge rising suddenly, *e.g.*, Vaalbank.

Banken, plural of *Bank*—

A term used to denote a step-like feature, hence *banken* type of scenery, *e.g.*, in the high veld portion of the Lydenburg district of the Transvaal, due to alternations of harder and softer beds with a low dip.

Berg, plural *Bergen*—

Mountain: the term 'de Berg' is especially applied to the great eastern escarpment of the Transvaal plateau.

Bosch—

Bush or wood, *e.g.*, Blaauwbosch.

Bult—

A low ridge with gentle and gradual rise and even outline.

Dam—

Reservoir or pond.

Dans—

A broad shallow valley, *e.g.*, Leeuwen Dans.

Donga—

A small ravine or wash-out caused by floods in soft ground.

A gully or dry watercourse with steep sides, synonymous with the Eastern terms *waddy* and *nullah*.

Draai—

A bend or turn (of a river or range).

Drift—

A ford or crossing of a river.

Duin, plural *Duinen*—

A sand dune.

Dwala—

A native term used in Rhodesia for a bare rounded knoll or ridge of rock.

Eiland—

Island, *e.g.*, Paarden Eiland.

Fontein—

A spring. Much used in place-names, *e.g.*, Bloemfontein, Wonderfontein, &c.

Gat—

A hole, *e.g.*, *Wonder-gat*, a term applied to a sink-hole in limestone formation. *Cyfergat*, a spot from which water trickles; a 'soak.'

Gouph (pronounced 'Cope')—

A Bushman word, meaning 'as dry as can be,' applied to a portion of the Western Karroo.

Heuvel—

A height or elevation, generally of small magnitude, *e.g.*, Kliphеuvel.

Hoek—

(i) The area enclosed by a bend in a river.
(ii) The upper end of a valley shut in by mountains.

Holte—

A hollow or depression.

Hoogte—

A height or elevation, generally of greater magnitude than a 'heuvel.'

Karroo—

A Bushman word [illegible] *Gárú*, meaning 'dry as a bone,' applied to country like the [illegible] Cape Colony (geologically or botanically).

Kasteel (literally Castle)—
A high peak or ridge, *e.g.*, Riebeck's Kasteel.

Kloof—
The head of a valley with steep sides.

Knoppie—
A little hill or knob.

Kolk—
A depression in a *laagte* or river course.

Kom—
A basin-shaped hollow.

Kop, diminutive *Kopje*—
A peak or little hill (literally head), *e.g.*, Zwartkopje, Witkopje; hence *Tafelkopje*, a flat-topped or table-mountain type of hill; *Spitzkop*, a sharply pointed type of hill.

Kopjes Veld—
A track of country characterised by numerous little hills.

Kraal—
An enclosure for cattle or goats, also a native home or village; *e.g.*, Makapane's kraal.

Krans or *Kranz* (often incorrectly written *Krantz*)—
The feature made by a hard rock in a precipice.
The precipitous face of an escarpment, *e.g.*, Kranskop, Kransberg.

Kuil—
A shallow valley or depression.

Laagte—
A very shallow valley in which the course of the drainage is ill-defined.

Mond—
Mouth (of a river).

Muur—
A wall or barrier.

Naauwte—
A narrow portion of a valley or constriction along a gorge.

Nek—
A high-level gap or pass in a range of hills, *e.g.*, Commando Nek, in the Magaliesberg.

Oog—
The 'eye' of a river, usually applied to the spring feeding a river, *e.g.*, in limestone areas.

Pan—
A depression below the general level of the land and into which the drainage is directed.

Panneveld—

Country characterised by numerous pans.

Plaat—

A wide surface of bare rock, *e.g.*, of granite, *e.g.*, Klipplaat.

Plat Kop—

A flat-topped hill or mountain.

Pont—

A ferry, *e.g.*, Lindeque's Pont, on the Vaal River.

Poort—

A low gap or short narrow gorge intersecting a range of hills = 'water-gap' of American geologists (lit. gate), *e.g.*, Krokodilpoort, Komati Poort, &c.

Poortje—

A little poort.

Punt—

(i) A point on the coast, or (ii) a spur of a mountain.

Puts—

A pit or well.

Rand—

A ridge or steep escarpment, generally of no great elevation, *e.g.*, Rooirand (red ridge), Boschrand, Gatsrand, Witwatersrand (hence 'The Rand'), &c.

Randje—

The diminutive of *Rand*.

Rug, plural *Ruggen*—

A ridge or series of ridges. The 'Ruggens' in Cape Colony is a plain much entrenched by rivers—a dissected peneplain.

Sluit—

A ditch or water-furrow.

Spitz Kop—

A pointed or conical hill.

Spruit—

A small river or rivulet.

Strand—

A beach or strand.

Tafelberg or *Tafelkop*—

A table-topped mountain.

Toren—

A tower (applied to a pointed hill), *e.g.*, Babylon's Toren.

Vallei—

A valley, often p[illegible] but distinct in meaning from, *vlei*.

Veld (incorrectly *Veldt*)—

Open uncultivated country—
Bush veld (D., Boschveld), bush country. Sometimes called Low veld.
High veld (D., Hoogeveld), high plateaux, about 5,000 to 6,000 feet above sea-level.
Middle veld (D. Middelveld). The intermediate mixed country, between High and Low veld.

Vlakte—

'Flats,' a wide tract of flat country or plain.

Vlei or *Vley*—

A flat tract of country or area of gentle slope which is periodically subjected to flooding; a wide pan of inconsiderable depth.

Vloer—

A 'floor.' This term has much the same meaning as *Vlei*.

Waterval—

Waterfall.

Class II.—*Names of Rocks and Minerals.*

Amande Klip (Almond-rock)—

Amygdaloidal lava.

Bacon-rock—

A term used by Barberton miners to denote the reddish cherty or jaspery variety of the banded ferruginous quartzite. (See *Calico-rock.*)

Banket—

A term applied to the Witwatersrand conglomerates on account of a supposed resemblance to an almond 'cake' made by the Boers.

Bantom—

A term used by alluvial diamond diggers to designate striped or banded pebbles (magnetite-quartzite or slate, or magnetite-jasper rocks).

Bar—

A term used by miners to denote a conspicuous band or seam of rock, distinguished by some character such as hardness or colour, *e.g.*, Red Bar.

Blaauw-ground (Blue ground), Kimberlite—

The unoxidised portion of the filling of the diamond pipes.

Blue Ground. See *Blaauw-grond.*

Bosjesman's Klip (Bushman's rock)—

A term applied to the Dwyka of Southern Cape Colony, owing to the jagged character of its weathered surface.

Calico-rock—

A term formerly used by the Marabastad miners for a banded magnetite quartzite, usually in alternating black and white bands.

Drip Kalk (Drip-limestone)—

Stalactitic material.

Float—

A term used by miners for surface frag[illegible] ...ock not *in situ*.

Floating Reef—

A term used by diamond miners for the masses of the 'country,' or foreign rock occurring in a diamond pipe.

Gruis—

Shale, mudstone, or soft variety of Dwyka.

Haar Klip (Thread-rock)—

'Crocidolite' or asbestos.

Hardibank—

A term used by diamond miners for a hard compact variety of 'blue-ground' very resistant to weathering.

Ijzer Klip (Ironstone)—

Applied most commonly to igneous rocks such as dolerite and diabase.

Kalksteen—

Limestone.

Klip—

A stone, or rock.

Olifant's Klip (Elephant's hide rock)—

Name given to the Dolomite formation owing to its mode of weathering.

Ou-Klip or *Oude-Klip* (Old rock)—

A secondary limonitic surface-deposit, a kind of laterite.

Turf—

A heavy black clayey soil or loam, very common in low-lying areas, overlying basic igneous rocks.

Vuursteen Klip (Firestone rock)—

Quartz, chert, flint, or very fine-grained quartzite.

Weer Klip—

Lit. weather-stone = meteorite.

Yellow Ground—

A term used by diamond miners for weathered, decomposed, or oxidised 'blue ground' in the diamond pipes.

Occupation of a Table at the Zoological Station at Naples.—Report of the Committee, consisting of Professor S. J. HICKSON (*Chairman*), Rev. T. R. R. STEBBING (*Secretary*), Sir E. RAY LANKESTER, Professor A. SEDGWICK, Professor W. C. MCINTOSH, Dr. S. F. HARMER, Mr. G. P. BIDDER, *and* Dr. W. B. HARDY.

THE Committee report that the Association's table at the Zoological Station at Naples has been occupied by the following investigators during the past session:—Mr. E. S. Goodrich, F.R.S., Mr. Geoffrey W. Smith, Mr. F. [illegible] and the Hon. Mary Palk.

The Hon. Mary Palk reports:—

I occupied the Naples table of the British Association for six months, from November 1909 until the end of April 1910. During that time I was working on the Polyzoa of the Bay of Naples, especially on a variety of *Flustra papyrea* (Pallas) with well-developed ovicells. I studied the structure of the œsophageal cells, which show transverse striations in the protoplasmic walls as mentioned by Henneguy, and the finer histology of the polypides, also certain bodies lying in the opercular tissue which seem to correspond with the glands described by Waters in calcareous polyzoa. I was not successful in tracing oogenesis, which must take place at a time of year when I was not there, as I could only find fully formed eggs and embryos and no ovary or young ova. I hope to continue these researches so as to establish the reproduction of the genus. I also made a fairly representative collection of the Polyzoa of the Bay of Naples, adding several Cyclostomata to the lists already published by Mr. A. W. Waters. I beg to offer my best thanks to the British Association for the use of the table, and to the staff at Naples for the kind help afforded to me.

Mr. Geoffrey W. Smith reports:—

I occupied the table from December 15, 1909, to January 1, 1910. During that time I was working on the effects of Sacculina on its host Inachus, especially with the object of obtaining the stages which show exactly how the gonad is absorbed as the result of the presence of the parasite. Owing to the very large amount of material supplied to me I have been successful in doing this, and also in definitely settling another point of some importance, namely, that the effect of the parasite is really the same on female as on male hosts, making the young female prematurely assume adult female characters. The results will be published in the 'Quarterly Journal of Microscopical Science.'

Mr. Methuen reports that during his stay at Naples he was working at the internal anatomy of Decapod Crustacea. He made a number of dissections of the alimentary canal of various types and preserved them for the purpose of working out the histology of the digestive glands.

Mr. E. S. Goodrich, F.R.S., reports:—

While occupying the British Association table at Naples from March 23 to April 11, 1910, I spent a considerable time carrying out feeding experiments with different colouring substances on young Amphioxus and studying the development of their nephridia in the hinder region of the pharynx. I also worked at the development of *Aricia fœtida* and preserved material for the embryology of this and other Polychæta. The results of the researches have not yet been published, being still incomplete.

The Committee, in concluding their report for 1909-10, wish to record their sense of the great loss to biological science caused by the death in September last of Dr. Anton Dohrn, the founder and director of the Zoological Station at Naples. Without referring to the high value of his personal researches in zoological science, the Committee may express their profound appreciation of [illegible] assistance and

cordial welcome that he invariably gave to the occupants of the British Association table at the Station. Dr. Reinhardt Dohrn succeeds his distinguished father as Director of the Station, and to him the Committee are already indebted for many acts of genial consideration and hospitality.

The Committee ask for reappointment, with a grant of 100*l.*

Index Generum et Specierum Animalium.—Report of the Committee, consisting of Dr. HENRY WOODWARD (*Chairman*), Dr. F. A. BATHER (*Secretary*), Dr. P. L. SCLATER, Rev. T. R. R. STEBBING, Dr. W. E. HOYLE, Hon. WALTER ROTHSCHILD, *and* LORD WALSINGHAM.

CONTINUOUS and steady progress has been made by Mr. Davies Sherborn in the preparation of Volume II. of this Index. Since the report for last year was sent in, Mr. Sherborn has dealt with the remainder of the separate works by authors whose names begin with C, and of these the various editions of Cuvier proved exceptionally long and tedious to analyse. Other works have also been dealt with as opportunity offered.

Valuable assistance has been rendered by Mr. Hartley Durrant, who lent from Lord Walsingham's library (presented to the Trustees of the British Museum) a fine copy of the extremely rare work by Billberg, 'Enumeratio Insectorum,' 1820, which has been indexed and made available for reference.

The slips, which are preserved in the British Museum (Natural History) by the kindness of the Trustees, are quite in order for those who wish to consult them, and are of exceptional value to anyone monographing a particular genus.

Mr. Sherborn and Mr. H. O. N. Shore have written a paper clearing up the difficulties surrounding Sowerby's 'Conchological Illustrations' and Gray's 'Descriptive Catalogue of Shells,'[1] and Mr. Sherborn himself has written on the dates of the parts of Burmeister 'General Insectorum,' 1838-46.[2]

Systematic and regular work on this Index is greatly encouraged by the friendly attitude of the Association, and the Committee, in recommending its own reappointment, earnestly ask the Association to continue this valuable help by a further grant of 100*l.*

The Zoology of the Sandwich Islands.—Twentieth Report of the Committee, consisting of Dr. F. DU CANE GODMAN (*Chairman*), Mr. D. SHARP (*Secretary*), Professor S. J. HICKSON, Dr. P. L. SCLATER, *and* Mr. EDGAR A. SMITH.

ANOTHER part of the 'Fauna Hawaiiensis' is about to be issued by the Committee. This will complete the descriptive part of the work. As it appears desirable to issue also a general summary of the Committee's work, the Committee ask to be reappointed without a grant.

[1] *Proc. [illegible]ac. Soc.*, September, 1909, pp. 331–340.
[2] [illegible] *Hist.*, January, 1910.

Zoology Organisation.—Interim Report of the Committee, consistin of Sir E. RAY LANKESTER (*Chairman*), Professor S. J. HICKSON (*Secretary*), Professors G. C. BOURNE, J. COSSAR EWART, M. HARTOG, W. A. HERDMAN, *and* J. GRAHAM KERR, Mr. O. H. LATTER, Professor MINCHIN, Dr. P. C. MITCHELL, Professors C. LLOYD MORGAN, E. B. POULTON, *and* A. SEDGWICK, Dr. A. E. SHIPLEY, *and* Rev. T. R. R. STEBBING.

THE Committee have not considered it to be necessary to summon any meetings during the past session, as no matters of special interest and importance to zoologists were raised.

The Committee ask to be reappointed without a grant.

Marine Laboratory, Plymouth.—Report of the Committee, consisting of Professor A. DENDY (*Chairman and Secretary*), Sir E. RAY LANKESTER, Professor A. SEDGWICK, Professor SYDNEY H. VINES, *and* Mr. E. S. GOODRICH, *appointed to nominate competent Naturalists to perform definite pieces of work at the Marine Laboratory, Plymouth.*

SINCE the date of our last report the British Association's table at the Plymouth Marine Laboratory has been occupied for one month (August 1909) by Mr. J. S. Dunkerly, for the purpose of investigating the life-history of the Flagellate Protozoa. The use of the table has also been granted, for the month of July 1910, to Mr. G. E. Nicholls, B.Sc., for the prosecution of his researches on Reissner's Fibre, with special reference to the Elasmobranchi.

Inniskea Whaling Station.—Report of the Committee, consisting of Dr. A. E. SHIPLEY (*Chairman*), Professor J. STANLEY GARDINER (*Secretary*), Professor W. A. HERDMAN, Rev. W. SPOTSWOOD GREEN, Mr. E. S. GOODRICH, Dr. H. W. MARETT TIMS, *and* Mr. R. M. BARRINGTON, *appointed to investigate the Biological Problems incidental to the Inniskea Whaling Station.*

MR. D. G. LILLIE was enabled to work at the Inniskea Whaling Station for several months during the summer of 1909. His expenses have been met by private benefaction. It was hoped that he would continue his researches this year, but, having been appointed a member of the scientific staff on the 'Terra Nova,' he left for the Antarctic in June. As a result of his work he has published substantial contributions to our knowledge of the Cetacea, and it is greatly to be hoped that the opportunity afforded by the Inniskea Whaling Station of investigating

the larger Cetacea will not be lost, as there seems every chance of these mammals being rapidly exterminated.

The Committee apply for reappointment and for a grant of 50*l.* to further the work.

Experiments in Inheritance.—Third Report of the Committee, consisting of Professor W. A. HERDMAN (*Chairman*), Mr. DOUGLAS LAURIE (*Secretary*), Professor R. C. PUNNETT *and* Dr. H. W. MARETT TIMS. (*Drawn up by the Secretary.*)

On the Inheritance of Yellow Coat Colour in Mice.

THE experiments have been much interfered with through disease among the mice. It has been necessary to destroy a very large number of them, and to commence again practically at the beginning. The present report is purely formal. A fuller report is anticipated next year.

The Committee ask to be reappointed without a grant.

Feeding Habits of British Birds.—Second Report of the Committee, consisting of Dr. A. E. SHIPLEY (*Chairman*), Mr. H. S. LEIGH (*Secretary*), Messrs. J. N. HALBERT, C. GORDON HEWITT, ROBERT NEWSTEAD, CLEMENT REID, A. G. L. ROGERS, F. V. THEOBALD, *and* Professor F. E. WEISS, *appointed to investigate the Feeding Habits of British Birds by a study of the contents of the crops and gizzards of both adults and nestlings, and by collation of observational evidence, with the object of obtaining precise knowledge of the economic status of many of our commoner birds affecting rural science.*

THE investigation of the feeding habits of the rook, starling, and chaffinch has been continued during the past year.

The correspondents whose names are set forth in the Report for 1909 have again sent specimens of birds to the Secretary each month. The Committee again desire to express indebtedness to them for their kind assistance.

During the twelve months (June 1, 1909, to May 31, 1910) 432 birds have been received, the number being made up as follows: rooks 87, starlings 193, chaffinches 152.

Each bird or batch of birds is accompanied by a form filled in by the correspondent giving details as set forth in the Report of last year.

The contents of the gizzards of 302 birds have been examined up to May 31, the number consisting of 212 rooks, 50 starlings, and 40 chaffinches. The evidence obtained from the examination of these specimens is not sufficient to form a correct estimate of the economic status of any one of the three birds under investigation; when, in the opinion of the Committee, a sufficient number of specimens of any

one species have been examined, the results of the tabulations and the particulars supplied by the correspondents will be arranged and published.

A grant of 5*l.* was made to the Committee by the Association in 1909, and in addition there was a balance from the grant of 50*l.* from the Board of Agriculture and Fisheries, carried forward from last year. The money has all been spent. The Committee ask for reappointment, with a further grant, and with the addition of Professors S. J. Hickson, F. W. Gamble, G. H. Carpenter, and Arthur Thomson.

The Amount and Distribution of Income (other than Wages) below the Income-tax Exemption Limit in the United Kingdom.—Report of the Committee, consisting of Professors E. CANNAN (*Chairman*), A. L. BOWLEY (*Secretary*), F. Y. EDGEWORTH, *and* H. B. LEES SMITH, *and* Dr. W. R. SCOTT.[1]

Introduction.

THE Committee, which was appointed at the Dublin meeting, have proceeded with their investigations and collected information during two years; and though a complete account of the amount of income with which it deals cannot be given, it is now possible to survey the ground and to make an estimate which it is believed is better founded than any previously made, and which is nearly as accurate as is possible in the existing state of official statistics.

It is customary to divide the aggregate of incomes of the inhabitants of the United Kingdom into three groups: first, those incomes which are subject to income-tax—*i.e.*, which are over 160*l.* per annum according to the definitions of the Income-tax Commissioners; secondly, those incomes which are received as wages and come under the cognisance of the Labour Department and are included in Estimates of Earnings of Manual Workers; and thirdly, an Intermediate Group, which is included in neither of the former. It is the aggregate of the income in this third group that the Committee have to estimate.

The procedure of the Committee has been to collect all the statistics relating to members of this group which are published officially or semi-officially, to apply to public bodies for data as to the salaries paid to their employés, and to apply to societies representing professional and other classes for any statistical information they had as to the numbers in such groups and their incomes. For other classes the Committee made direct applications for information in all quarters where it seemed probable that a response would be received. In this matter they were greatly helped by the Manchester Statistical Society, who conducted a careful and useful investigation in the neighbourhood of Manchester. The Circular of Inquiry which follows was used extensively for the collection of fresh data:—

SIR,—It is of great importance for many practical and scientific purposes to know the total of the National Income and the relative number of persons in

[1] Mr. W. G. S. Adams has resigned his membership of the Committee.

receipt of incomes of different amounts. The total may be divided into three classes: (*a*) amount subject to income-tax; (*b*) amount received as wages; (*c*) remainder. Fairly adequate information is extant for classes (*a*) and (*b*), but no serious inquiry, official or private, has been made in recent years as to (*c*), and this unknown amount is the subject of vague and misleading guesses. Absence of information on this subject is one of the most serious gaps in our national statistics, which are otherwise becoming fairly complete. The work of the Committee named above is to form a reasoned estimate as to the numbers and income of persons, where income from all sources is less than 160*l*. and does not arise from wages. Apart from persons in receipt of pensions, annuities, and dividends (as to whom the Income-tax Commissioners give some information), the class in question consists largely of *clerks*, teachers, shop assistants, &c. The Committee, having considered the practicable means of forming an estimate, is of opinion that the answers to the questions on the annexed schedule, which is being issued to a number of Companies and Corporations, would be of material assistance to them in their task, when used in conjunction with the Population Census and other information. The Committee will, then, be greatly indebted to you if you will fill in the details asked as to your Firm, Company, or Corporation, and return the form at your early convenience.

The returns will be used only for purposes of averages and will be regarded as *strictly confidential*; no name, whether of an individual or of a company, will be used in the report.

I am, &c.

CONFIDENTIAL.

Year and locality to which information applies..

Nature of business or occupation..

[If shop assistants in retail business or commercial travellers are employed, details should be given under the same headings on a separate page.]

A. *Number* of partners, managers, clerks, &c., who draw more than 160*l*. per annum.

Men.............................. Women..............................

B. *Number* of partners, managers, clerks, &c., who draw 160*l*. or less. (Do not include (i) workmen, porters, messengers, &c.—*i.e.*, those in receipt of wages—or (ii) clerks, &c., who do not give their full time to your business).

Men and lads.................. Women and girls..................

As regards B.

Total amount paid to these clerks, &c. . . . £..................

The above will give the essential information, but it is also important to fill in the following table :—

Number of clerks, &c. (under B), whose incomes fall within the following limits :—

—	Men and Lads	Women and Girls
£140 to £160		
£120 ,, £140		
£100 ,, £120		
£80 ,, £100		
£60 ,, £80		
£40 ,, £60		
Under £40		

CONFIDENTIAL.

Use this page for *shop assistants* only. Exclude clerks, artisans, and labourers.

A. Number who draw more than 160*l.* per annum.

Men............................ Women............................

B. Number who draw 160*l.* or less.

Men and lads.................. Women and girls.................

As regards B.

Total amount paid to these assistants per annum £..................

Number whose annual salaries fall within the following limits :—

—	Without Board or Residence		With Board or Residence	
	Men and Lads	Women and Girls	Men and Lads	Women and Girls
£140 to £160				
£120 „ £140				
£100 „ £120				
£80 „ £100				
£60 „ £80				
£40 „ £60				
£20 „ £40				
Under £20				

It is evident that there is no clear line of division between the wage-earning group which is dealt with by the Labour Department and the intermediate group. Salaries, especially those of lads and of young men, are very frequently less than wages, so that it is not a question of amount of annual income. Again, there is no simple distinction between clerical and manual work, for many occupations involve both. Further, such important classes as shop assistants and small shopkeepers might equally well be included in either class. But it is not a definition in accordance with the nature of the occupation that we must aim at, but rather a question of fact as to whether certain classes do or do not come under the cognisance of the Labour Department and are or are not included in the estimates of aggregate wages based on their statistics. The Labour Department, however, does not issue an official estimate of aggregate wages, and in the end it will be necessary for each statistician to decide to what classes of persons the data published by the Labour Department relate, to estimate the aggregate wages of such groups, and to place the remaining groups either in the intermediate or in the income-tax paying classes. From this point of view it is not essential to elaborate the grounds of the delimitation actually adopted, for all occupied persons must be, in fact, included in one or other of the classes, and it does not matter whether they are included as wage earners or as salaried, since the income allotted would be much the same in each group.

When we have separated out wage-earners, so far as the Population Census allows, from other occupied persons, we obtain the numbers shown in the following table :—

Number of Persons in the Three Groups.

Census of United Kingdom, 1901. *Occupied classes, other than manual labourers working for employers (over ten years old).*

—	Males—000's				Females—000's			
	England & Wales	Scotland	Ireland	United Kingdom	England & Wales	Scotland	Ireland	United Kingdom
1. Civil Service (Officers and Clerks)	42	4	6	52	14	2	2	18
2. Local Government Officers	26	3	4	33	11	—	1	12
3. Army Officers	13	1	1	15	—	—	—	—
4. Navy Officers	5	—	—	5	—	—	—	—
5. Clergy of all denominations	40	5	6	51	—	—	—	—
6. Barristers and Solicitors	21	4	3	28	—	—	—	—
7. Law Clerks	34	6	2	42	—	—	—	—
8. Doctors, Dentists, Veterinary Surgeons, Engineers, Surveyors, Architects	59	8	6	73	1	—	—	1
9. Teachers	59	7	7	73	172	17	13	202
10. Authors, Editors, Journalists, Shorthand Writers, Scientists, Painters and Sculptors	23	2	1	26	1	—	—	1
11. Photographers, Musicians, Actors	38	3	1	42	33	3	1	37
12. Merchants	5	1	2	8	—	—	—	—
13. Brokers, Auctioneers, Accountants	64	7	5	76	2	—	—	2
14. Salesmen and Commercial Travellers	66	10	4	80	1	—	1	2
15. Company Officers	2	—	—	2	—	—	—	—
16. Commercial and Industrial Clerks	308	38	19	365	56	16	3	75
17. Bankers and Finance	31	5	3	39	—	—	—	—
18. Insurance Clerks	21	2	1	24	—	—	—	—
19. Insurance Agents	34	3	1	38	—	—	—	—
20. Farmers	203	46	328	577	21	8	71	100
21. Other Agricultural Employers	8	1	—	9	—	—	—	—
22. Merchant Service, Officers	—	—	—	36	—	—	—	—
23. Railway Clerks	68	8	3	79	—	—	—	—
24. Telephone Clerks	14	2	—	16	9	2	—	11
Manufacture and Occupations not otherwise included :—								
25. Employers	225	32	9	246	23	3	1	27
26. Working on own account	269	13	4	286	241	29	8	278
Dealers and Shopkeepers :—								
27. Employers	133	20	16	169	14	2	2	18
28. On own account	218	15	13	246	90	13	11	114
29. Employed	469	62	49	580	161	37	31	229
30. Costermongers and Assistants	47	4	2	53	14	3	1	18
31. Sweeps (not assistants)	4	1	1	6	—	—	—	—
Totals	2,529	313	497	3,375	864	135	146	1,145

The inclusion of heading 30 and 31, and the further inclusion of gardeners working on their own account (26,000), and of showmen, &c. (15,000), and of 'missionaries, preachers, monks, sisters, &c.,' are open to question. An estimate for some of these is included in our final table.

The table just given classifies the persons returned as occupied in the census of 1901 in thirty-one classes. The classes contain in every case one or more of the census sub-headings. These sub-headings are grouped in an apparently arbitrary manner in accordance with the kind of information as to incomes which is available. The classification for England and Wales in the census is the same as that for Scotland, but that for Ireland differs in some important respects, and some approximation has been necessary to obtain correspondence. The list will only be completely intelligible when put alongside the census tables of occupation. Since this classification is extremely important, in order that our results may be understood, and be capable of improvement as further information accumulates or as the census classification becomes more useful, we give the actual sub-headings contained in our thirty-one classes. Those who are not so included are lumped together as manual workers.

The first eleven classes are included under the census headings—Government, Defence, Professional.

Class
1 Civil Service, officers and clerks.
2 Municipal, parish, and other local or county officers.
3 Army officers (effective and retired).
4 Naval officers (effective and retired).
5 Clergy and ministers of all denominations.
5a Missionaries, preachers, monks, &c.
6 Barristers and solicitors.
7 Law clerks.
8 Those professions for which definite preparation is required—*i.e.*, doctors, dentists, veterinary surgeons, engineers, surveyors, and architects. Nurses are not included.
9 Teachers.
10 A composite group of authors, editors, journalists, reporters, shorthand writers, persons engaged in scientific pursuits, and artists, as to whom we have no special information.
11 A similar group, where there is a larger proportion of semi-manual workers included—photographers, musicians, and actors.

The following eight groups are included under commercial occupations in the census:—

Class
12 Merchants.
13 Brokers, stockbrokers, agents, factors, accountants, auctioneers, house agents. A miscellaneous group concerning whom we have no special information.
14 Commercial travellers and a few salesmen and buyers not otherwise described.
15 A small group described as officers of companies, societies, &c.
16 Clerks. Under this heading are included according to the Instructions to the Census Clerks employed in classifying occupations (of which we have a copy) the following headings:—

Accountant (bookkeeper), accountant clerk, accountant's clerk, booker, bookkeeper, cashier, managing clerk, secretary (not private) other than bank, insurance, and others specifically included in other classes. Collector of accounts, debts, rents, or rates, &c., water clerk, auto-type worker, merchant's correspondent, phonograph writer, typist, copyist, shorthand clerk, and some others.

We learn that it was intended to include all clerks, whether in commerce or manufacturing industry, under this heading.

Class
17 Bankers and finance agents.
18 Insurance clerks.
19 Insurance agents and collectors.

The remaining classes are :—

20 Farmers and graziers.
This includes crofters in Scotland and peasant proprietors in Ireland. It does not include farmers' relatives working on the farm or bailiffs.
21 Here are included a number of gardeners, entering themselves as employers and proprietors of agricultural machines, &c.
22 Here we have included masters, mates, and an estimate for engineers (from table 52 of Appendix A to the General Report of the Census). It is to be noticed that seamen at sea are not always included in the total population.
23 Railway officials or clerks. This is not given in the Irish census, and we have approximated for the relatively small number there concerned.
24 Telegraph, telephone service, not including messengers or Government servants who come under class 1 or mechanics.

The next five classes are obtained from Orders 9 to 22 in the census classification, which contain the whole of productive industry and a great part of retail distribution. The first separation is between manufacturers (or makers) and dealers, which includes shopkeepers and assistants. This division is not made in the Irish census, except that most important classes of shops are given separately. It is not possible in general to distinguish between wholesale and retail distribution, but it is to be remembered that clerks, who are the main employés other than manual workers in wholesale distribution, are already included in our class 16.

The other line of division is between employers, those who are working for employers, and those who are working on their own account. In the General Report in the 1901 Census considerable dissatisfaction is expressed as to the result of this classification, but it may be observed that it appears to be correct in its main lines, since persons working on their own account are found in greatest numbers in precisely those occupations where common observation would lead one to expect them. (See the list in the table below.) There is no other means of estimating these numbers. It is quite possible that many persons describe themselves as employers who are, in fact, employed during part of their time, and, indeed, very many persons are both employers and employed. To this point we must return when we estimate the incomes of this group.

In class 25 are included all the persons returned as employers in the census orders, except those employers who are dealers or shopkeepers, who, together, form heading 27. Similarly, under 26 and 28 are included those working on their own account. In class 29 come those (other than clerks) who work for those employers who are dealers or shopkeepers. Finally, we include class 30—costermongers, whether employers, employed, or on their own account—and class 31—employer sweeps; for these two classes, presumably, are not included in the Labour Department's wage statistics, as they are not manual workers employed by others. We may here remark that we learn that shop assistants are not to be included in the current wage census, and we have therefore included them in the intermediate group.

A study of the census will show some other classes, all small, which might be included in our grouping, but even in the aggregate they will not be large enough to affect our estimate seriously, and may be left as part of the margin which may be included either in the intermediate group or the wage-earning group, and must be included in one or the other. Additional classes, however, 5*a* (missionaries, &c.) and 11*a* (showmen, &c.), are inserted in a further table (p. 195).

It must be remembered that the whole estimate is dependent on the census classification, that is, ultimately, on the occupations which persons returned themselves as following in 1901, and we have no means of going behind this classification, except in those few cases where there are independent statements of the numbers of persons in an occupation, and even then the difficulties of comparison are enormous. In the supplementary table annexed are given some details under our classes 25 to 29 in order that it may be seen what occupations provide the greatest number under these composite headings:—

Census—Further details.

Classes 25 & 26—Manufacturers, &c., England and Wales. 000's.

—	Employers	Working on Own Account	
		Men	Women
Roads	10	23	—
Rivers and Docks	3	4	—
Mines and Quarries	1	—	—
Blacksmiths	7	10	—
Metals	16	11	—
Ships	1	1	—
Vehicles	8	8	—
Precious Metals	8	13	—
Builders	57	49 *	—
Furniture	9	13	—
Wood	2	3	—
Glass	3	1	—
Chemicals, &c.	3	1	—
Leather, &c.	5	5	1
Paper and Printing	6	3	—
Cotton	3	—	—
Wool	3	1	—
Other Textiles	4	2	5
Clothes	25	57 †	183 §
Food	7	7	1
Tobacco / Beer and Spirits	3	—	—
Lodging-house- and Inn-keepers	16	55 ‡	47
Others	5	2	4
	205	269	241

* Carpenters, 17; painters, 11; plumbers, 5; builders, 5.
† Tailors, 16; bootmakers, 38.
‡ Coffee-house, 6; lodging-house, 4; publicans, &c., 44.
§ Milliners, 8; tailors, 5; dressmakers, 153; seamstresses, 15.

Classes 27, 28, 29—*Dealers and Shopkeepers, England and Wales.* 000's.

—	Employers		Assistants		On Own Account	
	Males	Females	Males	Females	Males	Females
Dealers	17	—	—	—	—	—
Ironmongers	5	—	20	2	4	1
Jewellers	1	—	3	2	2	1
Chemists	5	—	16	3	4	—
Booksellers and Newsagents	6	—	23	10	9	4
Clothiers and Hatters	4	—	15	4	3	1
Bootmakers	2	—	10	6	2	1
Haberdashers	1	—	5	1	1	1
Drapers	11	2	47	58	8	7
Hairdressers	4	—	17	12	12	—
Dairymen	3	—	22	3	10	2
Cheesemongers	3	—	9	1	4	3
Butchers	13	1	68	1	23	1
Poulterers	3	—	13	1	11	2
Corn Dealers	5	—	7	—	3	—
Confectioners	12	3	5	21	13	12
Greengrocers	5	—	15	5	20	6
Grocers	18	2	100	13	36	27
General Shopkeepers	1	1	9	16	12	11
Pawnbrokers	2	—	8	1	1	—

The following table shows the whole population over ten years old as it was in 1901:—

1901.—*Persons over* 10 *Years Old.** 000's

—	England and Wales		Scotland		Ireland		United Kingdom †		
	Males	Females	Males	Females	Males	Females	Males	Females	Persons
Included in previous table	2,529	864	313	135	497	146	3,385†	1,145	4,530†
Manual workers	7,628	3,308	1,078	457	906	401	9,934	4,165	14,099
Total occupied	10,157	4,172	1,391	592	1,403	547	13,319	5,310	18,629
Unoccupied	1,977	9,018	265	1,199	344	1,272	2,586	11,488	14,074
Total	12,134	13,190	1,656	1,790	1,747	1,818	15,905	16,798	32,703

* Children (if any) under ten years in Ireland returned as occupied are also included.
† For the United Kingdom the numbers are corrected, as far as possible, by including estimates for the Army, Navy, and Merchant Service afloat or abroad, from the General Report of the Census.

Most of our information as to incomes refers to 1909 or 1910. To bring the census table up to the end of 1909 we must add 8½ per cent. in accordance with official estimates. This shows 4,910,000 persons (4,530,000 × 1·085) in either the income-tax paying or in the intermediate group, and about 15,300,000 wage-earners, male or female. Actually we have assumed that the numbers in class 20 (farmers) have remained unchanged, and have added about 10 per cent. in the case of all the other classes; this gives a general increase of 8·6 per cent.

Number of Income-tax Payers.

We can approach this part of the problem from two points of view, for we can either estimate the number of tax-payers from the Reports of the Income-tax Commissioners, or estimate the number of tax-payers in each of our thirty-one classes. As regards the first, it is well known that the number of income-tax payers cannot be directly found from the Commissioners' Reports, still less can we find the number of persons who pay on so-called ' earned income,' which alone concerns us at present. It is not proposed to make a new estimate of this number, but we recall the following statistics from Mr. Bowley's evidence to the Committee on Income-tax (H. of C., 365 of 1906, especially page 223). It appears that there were in 1904 about 639,200 persons earning over 160*l.* in Schedules D and E. To this we must add 23,000 farmers (see page 26), making 659,200, and 5 per cent. to bring it up to the year 1909, making 682,000. To this should be added an estimate for the considerable number of persons who earn less than 160*l.*, but whose income from other sources brings them above the exemption limit. On the other hand, we find in the fifty-second Report of the Commissioners (page 139, note) that about 750,000 persons satisfied the Commissioners that they were entitled to pay only 9*d.* on the whole, or some part of their income, *i.e.*, there are at least 750,000 persons who have some earned income and a total income of between 160*l.* and 2,000*l.*, to this should be added the relatively small number of persons, part of whose incomes are earned, while the whole is above 2,000*l.*, and also the number who did not, owing to the shortness of notice in 1908, or for other causes, claim the reduced rate to which they were entitled. All these data are consistent with an estimate of 800,000, or rather more, as the number of occupied persons who pay income-tax, and we propose to adopt this estimate. If the Income-tax Commissioners give us more information in the future it can readily be used to make the necessary alterations throughout the remainder of our estimates. Subtracting these 800,000 taxpayers from the 4,900,000 occupied persons other than manual workers, we have the large number of 4,100,000 persons in the intermediate group. This is likely to be correct (subject to the definitions we are adopting) within 100,000. This number is considerably greater than those which have been hitherto adopted; but previous writers have not given their data, so that it is not possible to discover the cause of the difference. It is probable that a very large number (nearly 1,000,000) classified as working on their own account in our table have not been included in other estimates, and that some classes which may be regarded as manual-labour classes are included in our statements, but not in others. As already stated, this inclusion or exclusion would become unimportant if the aggregate of income, salaries, and wages were computed.

Numbers and Incomes in the Thirty-one Classes of the Intermediate Group.

We now proceed to discuss the incomes of our thirty-one classes. For some of these we have adequate information; for others we have

sufficient information to form an approximate estimate; for others we must proceed by results of common observation or by guesswork. It is intended throughout this part of our Report to show clearly the basis of our estimates, and to put them in such a form that it will be possible for each item to be amended if further information can be obtained. Our information is adequate as regards the Civil Service, Local Government, the Army, Navy, the clergy, elementary teachers, banks, and railway servants. It is sufficient for an estimate for clerks, farmers, and shop assistants. In some other cases, viz., professional, under our classes 6 and 8, and merchants, we may assume that the great majority pay income-tax. In the remaining cases we must do the best we can to find limits to the aggregate income, which will not contradict any of the general data we have. The weak point of previous estimates of this intermediate income has been that no attempt has been made to determine any limits within which the aggregate may be definitely expected to lie. The late Sir Robert Giffen and some other writers have been content to find a lower limit and say, for example, that there is *at least* 200,000,000*l.* in this group. Others, following the example of Dudley Baxter, who initiated this inquiry in 1868, have been content to make the best guess they could, without attempting to assign its precision. We propose, on the other hand, to state (wherever any check can be obtained) the superior and inferior limits of the number and of the average income of the non-tax-payers in each group, and hence to compute a measurement of precision of the aggregate.

The theory of probability, especially that part related to the Law of Great Numbers and the normal Curve of Error, will afford some help. In each case we have endeavoured to assign, in the light of all the information available, whether published in this Report or omitted as too confidential or for want of space, limits within which it seems highly probable that the true measurement must lie. The modulus in the Curve of Error shows the deviation which will only be exceeded in either direction once in six times in the long run, and we believe that we can assign the numbers, not differing greatly from such a modulus for the various classes. This does not mean that we can assign definite odds of five to one against the quantity measured being outside the limits we give, but that we can obtain numbers whose ratio to such a modulus will not differ greatly from unity. The numbers following the sign $\pm$ in our estimates are all to be interpreted in this sense.[1] Having obtained these moduli for all the items it is a known problem to combine them by the theory of error into a modulus for the total. Accordingly this section of the Report will be devoted to assigning estimates for each of the thirty-one classes, and then grouping them together.[2]

It must be clearly understood that the main purpose in this Report is to tabulate our knowledge or our ignorance as to the Intermediate Group

[1] We use the modulus here in preference to the 'probable error' or the 'standard deviation' which express smaller improbabilities.

[2] It should be understood that the estimates in this section of the Report have been made by the Secretary, who alone has had access to the information accumulated, and that the other members of the Committee have only given a general assent to them.

as definitely as possible, and to assign limits to the precision of the estimate of the *aggregate* income of this group. Every estimate should be criticised in the light of its effect on this aggregate, and if any amendment is thought necessary, its effect on the result should be computed before its importance is accepted. As a by-product we have also obtained valuable information as to special classes, but we are bound to make estimates in all cases whatever our ignorance may be. It is believed that the use of the modulus, chosen so as to include all estimates which are reasonably probable, enables us to make bricks without straw which will be strong enough for the strain we shall put on them.

Class 1. *Civil Service.*—There is no exact classification extant of the individual salaries of Civil Servants, but the numbers and the salaries are given in great detail in the estimates for the Civil Services and Revenue Departments published annually. The only difficulty is to interpret such items as '39 second-division clerks, minimum 70*l.*, annual increment 10*l.*, maximum 250*l.*, total 5,400*l.*,' and to estimate from them the number and income of those who have not more than 160*l.* It is believed that this has been done in such a way that the result, both in number and distribution of salaries, is very near the facts, and that it was unnecessary to try to get complete details from the Treasury. The process used is to take every item by itself, and divide the groups according to whatever indications are given. A further difficulty is to divide the wage-earners from the salaried, but the Census Instructions to Tabulating Clerks make it possible to select with very fair precision those who are included under the heading Officers and Clerks. As a result of our examination we find 56,000 male Civil servants (officers and clerks) in the United Kingdom, of whom about 19,000 received more than 160*l.* The Census total was 52,000, which, when increased by 9 per cent. to bring it up to date, corresponds closely with the total just found. The average salary of these clerks is, approximately, 95*l.* Our conclusion is that there are 36,000 ± 2,000 male clerks, with not more than 160*l.*, and that their average is 95*l.* ± 5*l.* As regards the women clerks, we only find 14,300, whereas the census gives 18,000. [The difference is not improbably due to many sub-postmistresses returning themselves as Government servants, whereas, in fact, they would be more properly classified as shopkeepers, and only receive part of their income from the Government. We have transferred these to class 27. Sub-postmasters and mistresses are not properly included as Government servants.] The main bulk of these female clerks are in the Post Office service. Only 175, or about 1 per cent., of these women earn more than 160*l.* The estimate we adopt under this heading is 15,000 ± 2,000, at 57*l.* ± 5*l.* In this and in other classes a small number pass the exemption limit in virtue of other sources of income. There is no means of allowing for this except by the limits shown by the 'modulus.'

Class 2. *Local Government.*—We have received in answer to our Schedule of Inquiry thirty-one detailed returns from county boroughs in England and Wales with an aggregate population of over 4,000,000, and a return from the London County Council. There is considerable difficulty in definition in this class, and it is improbable that the town clerks who made returns for us obtained exactly

the same line of division as the census authorities, either as to whether a person was or was not employed in local government service, or as to whether he was an official or a workman. A further difficulty is that many persons give only part of their time to such service, being engaged in professional occupations otherwise, and that they may in a few cases have been included with unduly small incomes. For Scotland we have returns from Glasgow, Edinburgh, Dundee, Perth, Paisley, Hamilton, and Cupar. We have no returns from counties as apart from boroughs. The total number for which we have information is 11,400 males and 1,560 females in Great Britain. We have no returns from Ireland. As regards males, 38 per cent. in London, 76 per cent. in the boroughs, and 76 per cent. in Scotland received less than 160*l.* The average of these in London was 120*l.*, in the boroughs 91*l.*, in Scotland 93*l.* Taking the census numbers and combining our estimates in proportion to the population of London, the rest of England, and of Scotland and Ireland, we find that 72 per cent. (*i.e.*, 26,000) receive less than 160*l.*, with an average of 93*l.* Different methods of combination would give different results, and it seems necessary to allow a margin ± 2,000 for the number, and ± 10*l.* for the average salary. As regards women and girls, we find that the proportion to men in our returns is less than in the census, no doubt because the census includes nurses in infirmaries, &c., while for our purpose they were excluded, together with other nurses in the Census Order 3, Sub-order 3. We have therefore in the final table included only one woman to seven men, as shown in the returns. Very few of them receive over 160*l.*—their average in London is 80*l.*, in the boroughs 46*l.*, in Scotland 50*l.*, and the approximation chosen is 5,000 ± 3,000 at 50*l.* ± 5*l.*[1]

Note.—It must be remembered that we have to deal with a very large aggregate, and in dealing with items which do not amount to £1,000,000, as is the case for women and girls in the two classes now dealt with, a considerable relative margin will have little absolute effect on our final estimate.

Class 3. Of Army officers, it appears from the Army Estimates that only about 800 receive salaries of less than 160*l.*, and their aggregate is 92,000*l.*

Class 4. In the Navy, sub-lieutenants, mates, cadets, clerks, and some others receive less than 160*l.* There are in all 1,475 of these, with an aggregate income of 115,000*l.* In both these cases it is reasonable to assume that retired officers have incomes above 160*l.*

Class 5. *Clergy.*—We have information in considerable detail as to many denominations, but it is not necessary to go into these minutely in view of the smallness of the aggregate non-taxpaying income. In the *Established Church in England and Wales* the net income is less than 160*l.* in about 4,000 benefices, and more in the remaining 10,000. The average salary of 7,200 assistant clergy is estimated to be slightly less than 150*l.* There are some 4,000 clergy, also, not attached to parishes. Of course, many of the clergy with the smaller benefices have independent means. The number we adopt is 7,000 ± 2,000 at 120*l.* ± 20*l.*

[1] The table which shows the estimates adopted is on page 195.

Ministers of other denominations number about 12,000, of whom we estimate that 7,500±2,000 are not subject to income-tax, and average 120*l*.±20*l*.

In Scotland there are some 6,000 ministers, of whom about 1,800 belong to the Established Church and 2,000 to the United Free Church. The great majority of the former and over 80 per cent. of the latter have incomes over 160*l*., and so far as we have details of other denominations it appears that similar statements would apply to them. We estimate that there are 1,500 ± 500 clergy with incomes 110*l*. ± 20*l*. below the income-tax limit. We have very little information as regards the salaries or receipts in Ireland, where there are some 3,500 Roman Catholic priests (of whom 1,100 are parish priests) and 2,500 ministers of other denominations. The greatest possible estimate, if all these were receiving exactly 160*l*., would be 960,000*l*., and the sum we need must be between this and nothing. It seems reasonable to take 3,000 ± 2,000 at 110*l*. ± 30*l*. The clergy in the United Kingdom then are estimated to contribute about 2,500,000*l*. to our total, and it is unlikely that it can be as much as 3,500,000*l*., or as little as 1,500,000*l*.

Class 5*a* contains monks, nurses, sisters, itinerant preachers, many of whom have no definite income. We include an estimate in the table which indicates that the aggregate is quite small.

Class 6. *Lawyers.*—In this and some of the following classes some assistance is afforded by the distribution by age given in the census. Though, of course, different persons going through a professional career arrive at an income of 160*l*. at different ages, yet there must be an average age at or near which a considerable proportion of such persons obtain an income of 160*l*., and so far as we can assign this average we can assign the number who have less than 160*l*. In the case of barristers and solicitors we take this age to be twenty-eight years, with margin of two years, and obtain 2,000 persons ± 1,000 persons not paying tax. We have no knowledge as to their income, but may put it as 100*l*. ± 50*l*. The total amount is small.

Class 7. *Law Clerks.*—We put the age at thirty years, with a margin of about four years. This gives us 30,000±4,000. Since 10,000 of these are under twenty, and the average income is therefore small, and somewhat smaller than in the Government service, where there are relatively fewer lads, we may take the income as 80*l*.±30*l*.

Class 8.—Under this heading are included those classes of professional men, other than lawyers, who go through a definite course of preparation. There are very few under twenty so given in the census. If we may assume that the average age for first paying income-tax is between twenty-five and thirty years, we should find 19,000 ± 5,000 not paying, and we may perhaps take their income as averaging 120*l*.±30*l*.

Class 9. *Teachers.*—As regards the teachers in public elementary schools in England, the returns of the Board of Education for 1908-09 give in great detail the numbers and, except in the case of supplementary, provisional, and pupil teachers, the salaries. We have collected more detailed statistics from the secretaries of the Education Committees of fifteen counties and forty-two of the larger boroughs in England and Wales. The proportion between men and women in our collection is

very nearly the same as in the more comprehensive official statistics, and if we assume, as we are justified in doing, that supplementary, provisional, and pupil teachers receive less than 160*l.*, the proportion of those earning over 160*l.* is nearly the same in both sets of statistics both for men and for women. We are therefore justified in using the average of the figures we have found for those earning less than 160*l.* Our conclusion is that of the teachers in the public elementary schools of England and Wales 7,000 men and 2,000 women receive more than 160*l.*, while 30,000 men and 123,000 women receive less than 160*l.*, the averages for these being 100*l.* and 76*l.*

As regards Scotland, we have detailed information only for Glasgow, Edinburgh, Aberdeen, Inverness, Ayr, and Dundee. We have also some official statistics as to salaries and details as to numbers which throw light on the question, and can be used in conjunction with the statistics for these boroughs; but we have to discount them to some extent for the probably lower salaries in the country districts and smaller places. The salaries in Scotland, especially for men, appear to be considerably higher than in England. It appears that there are about 1,500 men in the elementary schools earning over 160*l.*, and 4,500 others, the latter averaging about 120*l.* Very few of the women receive more than 160*l.*, while about 14,000 average 70*l.*

For Ireland we have detailed information in the official report (Cd. 3699) relating to 1906, from which it appears that only a negligible number of men and women receive over 160*l.* in the national schools, while 6,000 men and 7,000 women receive less, the average of men and women together being nearly 100*l.* For compilation we take it that the men average 120*l.* and the women 80*l.*

Putting these figures together for the United Kingdom, we find that in the elementary schools about 9,000 men and 2,000 women receive over 160*l.*, and 41,000 men and 144,000 women less, the averages being 105*l.* and 75*l.* We enter these in our table as a separate class.

There remain 30,000 men and 76,000 women teachers in schools other than elementary, whom we put in Class 9*a*. We have a little information about these, but it is not sufficient to give an exact result. We find, as we might expect, that the proportion both of men and of women in secondary and higher education earning over 160*l.* will be considerably greater than in primary education, except that allowance should be made for a large number of governesses receiving small stipends. In elementary education one man in five receives over 160*l.* We are of opinion that in higher education one man in two or one in three passes this limit, and that the remaining 15,000 to 20,000 average 120*l.* As regards the women we estimate from such returns as to graduate teachers, &c., as exist, that four per cent. in higher education, as against one and a half per cent. in elementary, receive over 160*l.*, but that of the remaining 75,000 very many receive quite small salaries, averaging less than in the elementary schools, and we will take the average at 60*l.*

As to Classes 10 and 11 we have no information, and even the definitions are doubtful. Class 10 contains those engaged in literary and scientific pursuits and artists, and may be estimated to include about 30,000 persons in 1909. Class 11 contains photographers, musicians, and actors, and may be estimated to include 46,000 males and 41,000

females in 1909. We may perhaps assume that in both cases the amount of 160*l*. is reached by men on an average between twenty-five and thirty-five years of age, and that the great majority of the women in Class 10 receive less than 160*l*. This gives 11,000±3,000 in Class 10, and we will put their average at 100*l*.±10*l*. Similarly we get in Class 11, for the men 20,000±8,000, with an average of 90*l*.±40*l*., and for the women and girls 39,000±2,000, with an average of 70*l*. ±30*l*.

Class 11*a* includes showmen and others, some of whom are not manual workers employed by others, and we give a rough estimate in the table, p. 195.

Class 12.—This small class of 9,000 merchants may be taken as contributing nothing appreciable to our intermediate group.

Class 13.—*Brokers.*—Among brokers, auctioneers, and accountants, when clerks are excluded, there can be little doubt that the majority pay income-tax. It will probably be safe to take the age corresponding to such payment as thirty years, with a wide margin, and so obtain 13,000 ± 5,000 men at an income of 120*l*. ± 30*l*., there being relatively few under twenty years old; we have also to include 2,000 women.

Class 14. *Commercial travellers and salesmen.*—From information received from the United Kingdom Commercial Travellers' Association and from the Commercial Travellers' Benevolent Institution, it appears that there are from 30,000 to 50,000 men who satisfy the definition of 'a person engaged in representing a manufacturer, merchant, or wholesale house for the purpose of securing orders.' Of these it is supposed that about 75 per cent. make over 160*l*. There remain from 60,000 to 40,000 other persons included in the census as travellers. These are probably engaged in canvassing for retail firms, and for other subordinate purposes, and it is probable that the great majority make well under 160*l*. We may expect that there are from 30,000 to 50,000 in all who make over 160*l*., but in view of the uncertainty as to this denomination we had better take the margin as ± 15,000, while the number is taken as 52,000. As regards the average income it must be remembered that a very great majority of these are over twenty years, and are in a position superior to that of a shop assistant. We may therefore take their income as 100*l*.± 30*l*.

In Class 15, *officers of societies and companies*, we will take it that the great majority have an income-taxpaying income.

Class 16. *Commercial and industrial clerks.*—We have returns which are given in some detail in the tables on pages 186 and 187, from 102 firms carrying on a great variety of businesses scattered throughout the kingdom, and of very different sizes. These firms employ about 16,000 male clerks, and about 2,600 girls and women. This number of clerks, and still more the number of firms, seem at first sight ridiculously inadequate for our purposes, in view of the facts that there are over 300,000 employers in our Class 25, a large proportion of whom presumably employ one or more clerks, and there are 480,000 persons to be accounted for under the heading. But it often happens that quite a small sample is sufficient to give a measurement, which, though not exact, at any rate has

a precision which can be assigned. In the schedules which were filled up, the employers—except in the case of companies—included themselves as making over 160*l.*, but it seems better to adjust the schedules by subtracting 1 in every case from those receiving over 160*l.*, and then treat them as relating only to clerks and other subordinates. In the small firms this is generally accurate, and in large ones it makes practically no difference to the further argument. When this is done, the proportion of those receiving over 160*l.* to the total number employed is written down in each of the 102 classes. The result is given in the table, p. 189. It now appears that the grouping of these proportions shows the kind of regularity which is to be expected when samples are taken at random from a definite group. Instances, in fact, as shown in the table, agree fairly closely with the distribution shown by the normal curve of error. Looked at from this point of view it appears that from 1 in 5 to 1 in 3, on an average, of clerks in this class may be expected to receive over 160*l.* Noticing that in the larger firms the proportion is on the whole smaller, and that when all the firms for which we have returns are massed together the proportion falls to 0·21, and aiming at a weighted average since the larger firms have greater importance, we come to the conclusion that the proportion is probably between 1 in 4 and 1 in 5, *i.e.*, between 0·20 and 0·25. We will widen this margin for safety and say, then, that 0·23 $\pm$ 0·06 of male clerks and similar employés pay income-tax, and that therefore 0·77 $\pm$ 0·06 of 406,000 (the whole number in this class), *i.e.*, 312,000 $\pm$ 24,000, are below the income-tax limit. The average income for those for whom we have returns is 78*l.*, and we assign the margin $\pm$ 10*l.*

As regards women, the proportion to men in our returns is nearly the same as shown by the census. The number who pay income-tax is very small, the average income shown is 45*l.* We therefore adopt the number 81,000 at 45*l.* $\pm$ 10*l.*

As will be seen from the detailed table, it would be possible to make a carefully weighted average allowing different importance to the different occupations, but after careful consideration it is considered that no greater accuracy would be obtained. Of our 102 returns 27, 21, and 14 are from the neighbourhoods of Manchester, Birmingham, and London respectively, 10 from the rest of England and Wales, 21 are from Ireland, and 9 from Scotland. London is represented rather in Classes 17 and 18.

17. *Bank Clerks.*—Thanks to the Central Association of Bankers we have obtained detailed information as to about 30 per cent. of the bank clerks of England and Wales. For Scotland we have information as to about 80 per cent., and for Ireland we have a less detailed statement, which is stated on good authority to be typical for the country, and which simply gives the proportions of clerks who receive over 160*l.*, from 100*l.* to 160*l.*, and less than 100*l.* The details, which are summarised on p. 188, are highly confidential, and we cannot go into them. They result in the following numbers, which may be regarded as being accurate within the limits stated: 24,000 $\pm$ 1,000 at 89*l.* $\pm$ 5*l.* This corresponds to the receipt of an income of 160*l.* at the age of thirty-two years on an average.

Details as to Firms employing Clerks.

—	Males: Receiving over £160	Males: Receiving under £160	Females: Receiving over £160	Females: Receiving under £160
Architect	2	3	—	1
Auctioneer	2	4	—	—
Insurance Broker	2	1	—	—
Stockbroker	2	2	—	—
Accountants	6	20	—	6
"	8	15	—	2
"	5	10	—	—
"	3	7	—	2
"	4	2	—	—
Merchants	10	34	—	3
"	26	81	—	17
"	25	82	—	2
"	55	152	—	—
"	36	128	—	—
"	17	24	—	1
"	12	8	—	5
"	13	16	—	—
"	3	7	—	2
"	4	2	—	—
Coal Mines	48	81	—	1
" "	15	61	—	—
Precious Metals	3	—	—	17
" "	3	1	—	14
Fancy Metal Goods	2	4	—	10
Moulders	3	2	—	—
Ironfounders	4	36	—	16
Engineers	51	89	—	16
Iron and Steel	17	88	—	—
Engineers	48	189	—	18
Electrical Engineers	206	710	—	72
Engineers	9	12	—	4
Machine Makers	6	14	—	3
Textile Makers	38	85	—	19
Cycles	18	137	—	86
Metal Workers	23	117	—	30
Galvanisers	18	44	—	1
Swords	1	1	—	—
Lead, Glass, &c.	62	533	—	100
Brass Goods	7	5	—	3
" "	7	4	—	—
Brassfounders	23	36	—	13
Engineers and Shipbuilders	12	16	—	2
Electric Works	136	403	—	78
" "	11	18	—	—
Shipowners (ashore)	39	34	—	7
"	16	109	—	7
Cotton Spinners	5	9	—	10
" Weavers	6	13	—	—
Wool Weavers	29	19	1	—
Linen	60	165	—	16
"	8	14	—	—
Jute	2	4	—	—
"	5	7	—	—
"	11	4	—	—

Details as to Firms employing Clerks—continued.

—	Males: Receiving over £160	Males: Receiving under £160	Females: Receiving over £160	Females: Receiving under £160
Textile Merchants	100	762	—	35
" "	46	179	—	6
Drapery (Clerks)	6	25	1	13
" "	131	414	8	245
" "	38	53	9	27
" "	10	40	—	93
Waterproofing	25	96	—	10
Provision Merchants or Manufacturers	4	20	—	—
" " "	8	11	—	1
" " "	8	—	1	10
" " "	6	4	—	8
" " "	87	82	—	—
" " "	51	222	3	68
" " "	8	77	—	10
General Manufacturers	488	3,510	—	1,241
" Merchants	7	20	—	6
Tobacco	83	85	2	1
Beer and Spirits	115	169	—	5
" "	7	6	—	1
" "	7	8	—	—
Harbours	26	61	—	—
"	26	20	—	—
Printers, &c.	12	72	—	16
Builders	10	8	—	4
Furnishers	1	1	—	—
Gas	27	52	—	1
"	8	29	—	—
"	1	8	—	—
Warehousemen and Packers	55	354	—	33
" "	232	1,095	—	20
" "	3	8	—	—
" "	162	326	—	—
" "	24	105	—	—
Miscellaneous Manufacturing and other firms	5	7	—	3
" " "	8	5	—	1
" " "	6	34	—	1
" " "	1	2	—	—
" " "	9	1	—	1
" " "	3	10	—	—
" " "	4	8	—	—
" " "	5	3	—	4
" " "	7	18	—	—
" " "	243	609	—	135
" " "	25	179	—	—
" " "	9	8	—	2
" " "	9	11	—	1
" " "	4	14	—	—
" " "	14	15	1	—
" " "	2	5	—	6
" " "	5	3	—	4
	3,363	12,524	25	2,586

Details as to Firms employing Clerks—continued.

—	Males: Receiving over £160	Males: Receiving under £160	Females: Receiving over £160	Females: Receiving under £160
Insurance Companies	60	121	—	5
" "	6	33	—	4
" "	944	422	—	392
" "	5	4	—	—
" "	31	24	—	—
" "	4	2	—	1
" "	1	42	—	26
" "	35	37	—	8
" "	369	548	—	30
" "	29	26	—	5
" "	1	1	—	1
" "	2	3	1	2
" "	9	23	—	—
" "	2	3	—	—
" "	89	190	—	23
" "	32	108	—	—
	1,619	1,585	1	497
Banks	121	500	—	—
"	218	583	—	—
"	275	511	—	—
"	267	649	—	—
"	251	521	—	—
"	159	490	—	—
"	35	56	—	—
"	22	22	—	—
"	1,330	1,562	—	—
"	311	352	—	—
"	179	273	—	—
"	59	71	—	—
"	312	549	—	—
"	118	258	—	—
"	74	88	—	—
"	160	318	—	—
"	55	30	—	—
"	1,523	1,246	—	—
"	44	65	—	—
"	216	311	—	—
"	15	35	—	—
	5,744	8,490	—	—
Railways	369	4,189	—	136
"	914	8,925	—	27
"	724	7,281	1	143
"	43	465	—	30
"	228	2,800	—	60
"	139	2,756	—	74
"	23	458	—	11
	2,440	26,874	1	481

If $m+1$ is number of males receiving over 160*l.* and n is number of males receiving 160*l.* or less, and $p=\frac{m}{m+n}$, the *values of p* for 102 firms are as follows:—

·0	·0	·0	·0	·08	·08				
·10	·11	·11	·12	·12	·12	·13	·13	·13	
·14	·14	·15	·16	·17	·17	·17	·17	·17	
·17	·18	·18	·18	·19					
·20	·20	·20	·20	·20	·20	·20	·22	·22	·22
·22	·23	·23	·23	·23	·24	·24	·25	·25	·25
		·26	·26	·26	·27	·28	·28	·28	·29
·30	·31	·31	·32	·33	·33	·33	·33	·33	·36
·36	·36	.37	·38	·39					
·40	·40	·40	·41	·41	·42	·42	·43	·46	·49
·50	·50	·50	·50	·51	·53	·53	·55	·56	·56
·56	·56	·58	·58						
·60	·60	·60	·67						
·71									
·89									

Median	·265
Unweighted Average	·305
Weighted Average	·21

Comparison with normal curve of error.

Modulus $c = 0{\cdot}25$; centre $0{\cdot}265$.

		Theory	Observation
		1	1
	$+1{\cdot}8c$		
		2	2
	$+1{\cdot}4c$		
		5	13
	$+1{\cdot}0c$		
		12	10
	$+0{\cdot}6c$		
Average		19	17
	$+0{\cdot}2c$		
		23	24
	$-0{\cdot}2c$		
		19	27
	$-0{\cdot}6c$		
		12	5
	$-1{\cdot}0c$		
		8	4

Class 18. *Insurance Clerks.*—We have detailed information, which is summarised on p. 188, as to about 10 per cent. of these. Though this is a considerable proportion, yet it has not led to results of great precision, because one or two large companies which have made returns show results divergent from the smaller ones. We adopt for our number 14,000 ± 2,000 at 87*l.* ± 5*l.*

Class 19. *Insurance Agents.*—We have no information as to this class, except common observation that they are not highly paid. Of course, they depend mainly on commissions. We take it that rather more than half pay income-tax, that, in fact, the number required equals the number over thirty-five years of age. It results that 19,000 ± 5,000 come within the non-paying class, the largeness of the margin corresponding to the want of information. We may put the earnings at 100*l.* ± 30*l.*

20. *Farmers.*—We do not presume to determine precisely the average income of farmers, a task which has always proved beyond the powers of statisticians, but it is necessary to make some estimate to fit in to our general scheme. After the Commission on Agricultural Depression in 1894, where evidence was given which showed that farmers' profits averaged about 26 per cent. of their rent, it was decided that profits should be assumed to be one-third of rent. We do not feel justified in taking this assumption as representing the average, partly because fewer than three hundred farmers choose the alternative of assessment under Schedule D, depending on their actual profits, and we only use it for estimating the relatively small number of farmers paying income-tax, and as a check on further estimates.

In the Reports of the Income Tax Commissioners relating to Schedule B we find the aggregate of farmers' incomes, which, reckoned at one third of rent, are over 160*l.*, and an aggregate of the rest of farmers' income assessed, but exempted from tax. The first aggregate was 5,000,000*l.* for Great Britain in 1907-08, corresponding to 15,000,000*l.* rent. Besides these figures we have in the return from the Board of Agriculture of 1895 (Cd. 8502) the number of holdings of various sizes in that year. These two things together lead to an estimate of the average rent per acre, for if more than 1*l.* 12*s.* per acre is assumed, farms of less than 300 acres would pay income-tax, and then the acreage of the holdings included would show more than 15,000,000*l.* rent. If, on the other hand, less than 1*l.* 12*s.* is assumed the figures fail to be consistent in the opposite direction. Of course, the rental from farms of the same size varies enormously, but we speak only of an average. We therefore take it that the average rent per acre is 1*l.* 12*s.*, as reckoned for income-tax purposes, in spite of the fact that this is more than was estimated by Mr. Thompson in a paper to the Statistical Society in 1907. There were 20,000 holders in Great Britain of more than 300 acres, and we will take this to be the number who pay income-tax. In the case of farmers, we are assuming that there has been no increase in numbers since 1901. We have then 258,000, according to the census classification, not paying income-tax. This corresponds to the number of holdings between 20 and 300 acres in which the aggregate is 21,700,000 acres, and the average is about 80 acres. The average rental income 1*l.* 12*s.* an acre is 128*l.*, the aggregate 35,000,000*l.* The amount reviewed by the Commissioners and exempted from tax corresponded to a rental of 26,400,000*l.*, which (on the same basis) would accrue from the aggregate of holdings between 50 and 300 acres. Presumably the profits of small holdings are not returned by the tax-surveyor. No one will believe that the average income of farmers holding 300 acres and under is as little as 43*l.*, *i.e.*, one-third of the average computed rental. It is just conceivable that the cash income may not be much greater, but in such a case considerable value of the produce grown is consumed at home by the farmer and his family, who are also provided with a house. We shall probably be on safe ground if we take the average income for this group as 60*l.* $\pm$ 30*l.*, that is the average profit per acre is between 7*s.* 6*d.* and 22*s.* 6*d.* The average income does not seem absurdly low in view of the fact that 86,000 of the farmers have between 20 and

50 acres only. Perhaps part of the profits from the 2,000,000 acres of agricultural land in holdings of from 1 to 20 acres in Great Britain should be added to our final estimate; but much belongs to persons already included, and forms part of their estimated incomes.

If we work out the statistics for Ireland on the same basis as for Great Britain so far as possible, we find that 590,000*l*. pays income-tax, and 2,530,000*l*. is exempted. There are 14,700,000 acres cultivated in Ireland. If the whole of this is reviewed by the tax-surveyors this gives 1*l*. 12*s*. rent per acre, if some of it is not reviewed it gives more than 1*l*. 12*s*. an acre. We will, therefore, make an estimate as if the average rent was 1*l*. 12*s*. an acre, as it is in Great Britain. On this assumption 1,200,000 acres, in holdings of 300 acres and over, pays tax, and belongs presumably to between 2,000 and 4,000 persons.[1] The remainder, if we adopt the census figures, is held by nearly 400,000 persons, and this is nearly equal to the number holding between 5 and 300 acres, the average size of these holdings being 40 acres, which, on the same basis, is yielding somewhat under 21*l*. a year. But, of course, in the small holding of Ireland the peasant lives to a great extent on his produce, and we must put aside these numbers as in the case of England, and make a pure assumption as to their real earnings; we will take it that the Irish peasant averages 30*l*. ± 15*l*. a year, the value of produce sold or consumed from his land, *i.e.*, from 7*s*. 6*d*. to 22*s*. 6*d*. per acre. Where the peasant carries on another occupation the sum named will be purely additional to the amount received from the other occupation, or already accounted for in another class. The cases where the joint income is over 160*l*. may be neglected.

Class 21. *Agricultural Employers.*— These are partly machine proprietors and the like, but mainly gardeners, nurserymen, seedsmen and florists. In the absence of information we will assume that half of this group of employers pays income-tax and the other half does not, but has an income comparable with that of skilled artisans. In any case the aggregate is not great.

Class 22. *Officers of the Merchant Navy.*—From p. 306 of the General Report of the Census of England and Wales in 1901, details are given of the number and ratings of seamen, who should naturally be counted as citizens of the United Kingdom, but are absent for the most part on census day. The persons that come into our class are the masters, mates, engineers, head stewards, and doctors. In the census the engineers are not separated from firemen. We assume, in accordance with the only detailed return we have, that the number of engineers is slightly greater than the number of mates, and allowing for the increase since 1901 we have 40,000 persons in this class. We have only three returns from shipping companies, one of which gives 312 out of 1,101 officers as receiving over 160*l*., the second 111 out of 330, and the third 60 out of 720. In the third case there are a very large number of fourth officers and junior engineers receiving less than 60*l*., and it is very unlikely that this is the proportion in the merchant service

[1] Fewer than 4,000 persons, for the average must be under 300 acres; more than 2,000, for the official statistics show 1,544 persons as holding more than 500 acres, while there are nearly 8,000 persons in the group next given as holding from 200 to 500 acres.

as a whole. The first and second returns give nearly the same proportion and nearly the same average under 160*l.* Adopting these two returns as typical, but allowing a wide margin because of the third return, we will take it that 30,000 ± 3,000 receive less than 160*l.* and average 100*l.* ± 30*l.* In this class, of course, food and room afloat is provided in addition to salary, but in such cases the value received does not rank as income in the definition of the Income Tax Commissioners, and we do not propose to include in our estimate the value of board and lodging in this and other classes where it is given in addition to salary, though we have included some receipts in kind in the case of farmers who produce for themselves.

Class 23. *Railway Clerks.*—We have been very fortunate in obtaining information as to 29,300 railway clerks and officials out of about 83,000 in Great Britain. We have no information as to Ireland. The railways from which we have returns in England and Wales will, it is believed, give nearly the same distribution and average as all would. Returns for Scotland are more complete, including 6,000 clerks and officials out of about 9,000. In grouping these together we have treated Scotland and England separately, and assumed that the Scottish returns would apply to Ireland, when allowance is made for the different totals in the two countries, and then put them together in proportion to the numbers employed in the three countries. The result is that 9,000 ± 2,000 receive over 160*l.*, and 78,000 ± 2,000 under, and these latter average 82*l.* ± 5*l.*

Class 24.—This class consists almost entirely of telephone and telegraph clerks, other than those employed by the Post Office. We may take it that the run of salaries is somewhat lower than for commercial clerks, and as the whole class is small it is not necessary to aim at great precision. Our estimate is given in the table on p. 195.

In Classes 25 to 29 we deal with all the manufacturers, shopkeepers, and dealers in productive and distributive industry not included in the previous classes, and not costermongers. The great difficulty is the complete lack of information, and also the doubtfulness of the division between persons returning themselves as employers and those returning themselves as working on their own account. In view of the number of commercial clerks which we have already dealt with it seems quite certain either that the number of employers is inflated, or that many employers are on so small a scale that they do not employ a single clerk.

Class 26.—It appears safe to assume that the great majority of those working on their own account, of whom some detail is given in the table on p. 176, are making less than 160*l.* a year. Thus the manufacturers include a great number of blacksmiths, carpenters, tailors, and bootmakers among the men, and of dressmakers among the women. It is safe to assume that these men are making something between the wages of skilled and unskilled men on an average, and we therefore put them at 80*l.* ± 20*l.* Dealing similarly with the women, and allowing a large margin in view of the fact that a great number of badly paid workers may be included, we may put the average as between 20*l.* and 60*l.* These estimates are sufficient for Class 26.

Classes 27 and 28. *Dealers and Employer-shopkeepers.*—The 17,000 dealers may be taken as paying income-tax. There are left 194,000 shopkeepers, including here 5,000 transferred from the Civil Service, see p. 180. The only information we have bearing on shopkeepers is the assessed value of residential shops, and the income-tax surveyors, of whom we have inquired, maintain that the assessed value of a shop has no relation to the income as a shopkeeper, though, in fact, the two or three estimates they reluctantly made were practically identical. It is assumed in the Income Tax Act that in the case of a residential shop one-third of the assessed value should be counted as residence; also it is generally assumed that rent is from one-eighth to one-tenth of income for incomes of about 150*l*. If we make these two assumptions together we find that the assessed value of a residential shop, 50*l*., corresponds to an income of 160*l*., and it is not improbable that the number of shopkeepers who reside at their shops subject to income-tax is equal to the number of residential shops assessed at 60*l*. or more in London, and 50*l*. or more in other parts of the United Kingdom. In the Fifty-third Report of the Commissioners of Inland Revenue, p. 93, we have the necessary particulars, except for Ireland; taking the number for Ireland as equal to that for Scotland (738), we find about 80,000 residential shops in the United Kingdom above the limits of assessment named. To these we should add a small number of non-residential or 'lock-up' shops. We suggest 80,000 ± 30,000 as the number of shopkeepers paying tax. There remain about 230,000 assessed at between 20*l*. and the values named. Of these, about 114,000 would (from the census figures) be employers, and 116,000 on their own account, if all employer-shopkeepers had shops assessed at over 20*l*. There would remain about 280,000 on their own account assessed at less than 20*l*. Without depending on this assumption, we will take it that the employer-shopkeepers average between 70*l*. and 150*l*., and those on their own account between 40*l*. and 140*l*., for the averages are by assumption under 160*l*., and these people make a living, and if in Class 27 employ others.

Class 25.—If reference is made to the table showing some detail of the employers in manufacture, &c., it will be seen that many are in quite a small way; in particular, blacksmiths, those producing clothes or food, some builders, some engaged on rivers, and some engaged on roads (a heading which includes small cab-proprietors), will easily account for about 30 per cent. of the whole of the class as not paying income tax. We may suggest 208,000 ± 60,000 as paying, and 93,000 ± 60,000 as not paying tax, and assign to these latter the same income as in Class 27. As regards these very uncertain estimates in Classes 25 to 28, it must be remembered, as already stated, that we know the total of those paying income-tax approximately, and it is only a question of distributing them among the right classes. If we have taken too many in Class 27 it will follow that we have taken too few in Class 25, and so on. The range of income assigned, for those with less than 160*l*., is, it is thought, wide enough to cover the uncertainty.

Class 29.—*Shop assistants.*—We have three different returns, one covering 15,000 shop assistants, with an average of 61*l*. per annum in cash, one from quite a small group of special firms, covering 1,900

persons, with an average of 68*l.*; and a third—a very important compilation kindly handed to us by the Financial Secretary of the National Amalgamated Union of Shop Assistants, relating to 3,171 persons, whose average cash income is 74*l.* In the first and third cases something would have to be added for about 22 per cent. of the assistants in the one group and 16 per cent. in the other who live in, or have meals in, if we were including such payments. Further information is given in 'Industrial Co-operation' by Miss C. Webb, 1904, where the range of earnings of the branch managers and countermen in the Co-operative Retail Distributive Societies are given in some detail relating to over 10,000 employés; the data are not sufficient for a perfect calculation of the average, but it cannot be very far from 68*l.* We have these four different estimates relating to a variety of districts and trades, and all being contained in the limits, 67*l.* ± 7*l.* Nevertheless, we think that this wage is rather higher than the one we ought to adopt for the 900,000 persons in Class 29, since many of these are probably engaged at very low salaries in shops from which no information was obtained in any of the returns. We therefore prefer to take 65*l.* ± 15*l.* as the average annual wage. We have practically no information as to the number of shop assistants who receive over 160*l.*, but it is certainly extremely small, and we take it as about one per cent.

Class 30. *Costermongers.*—This class includes all kinds of street sellers and hawkers. Probably none of them pay income-tax. We may divide them as lads under twenty, average perhaps 20*l.* a year; men of over twenty receiving somewhat more than the wage of unskilled labour, on an average, say, 70*l.*, with a wide margin; and women at perhaps 30*l.* This gives an average of about 50*l.*, and we will take it as between 40*l.* and 70*l.*

Class 31. *Sweeps (employers).*—None need be counted as paying income-tax, and the average may again be taken as between the wages of totally unskilled and of highly skilled labour. We put it at 70*l* ± 30*l.*

In the table on p. 195 the estimates we have now made are tabulated in detail. In the columns 1 and 2 are given the number of persons estimated from the census of 1901 raised by 10 per cent. throughout, except in the case of farmers, whose numbers are left unaltered; including farmers, an increase of 8·6 per cent. is allowed, which is about the increase of the whole population up to the end of 1909. Columns 3 and 4 give the number paying and not paying tax respectively, and column 5 the margin assigned. Column 6 gives the average income of those not paying, column 7 its margin. Column 8 gives the aggregate of the estimates assumed correct.

The total of the numbers we have found subject to income-tax is 900,000, while, if all the margins are added together and all taken as positive, they amount to 212,000. Compiled, however, by the theory of error, as explained below, the margin suggested is about 75,000, and is almost entirely due to that of Classes 16, 25, and 27. If the estimate of 800,000 income-tax payers be correct, we have put rather too many in each of these classes, and they should be transferred to the intermediate class.

Results.

	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
———	Census Numbers up to date		Paying Income-tax	Not Paying Tax				Aggregate	
	Males	Females		Nos. n	Modulus c	Av. Income s	Modulus k	Amount $A=ns$	Modulus K
	000's		000's	000's				£00,000's	
1. Civil Service	57	—	21	36	2	£95	£5	34	3
	—	15	0	15	2	57	5	9	1
2. Local Government	36	—	10	26	2	93	10	24	3
	—	5	0	5	3	50	5	2·5	1·5
3. Army	16*	—	15*	1	0	115	0	1	—
4. Navy	6*	—	4·5*	1·5	0	78	0	1	—
5. Clergy	56	—	35	21	4	120	20	26	7
5a. Missionaries, &c.	9	15	0	24	2	40	20	10	5
6. Lawyers	31	—	29	2	1	100	50	2	1
7. Law clerks	46	—	16	30	4	80	30	24	10
8. Professions	80	—	61	19	5	120	30	21	8
9. Elementary teachers:									
Male	50	—	9	41	2	105	10	43	5
Female	—	146	2	144	1	75	10	108	14
9a. Other teachers:									
Male	30	—	13	17	3	120	20	20	5
Female	—	76	3	73	1	60	20	45	15
10. Authors, &c.	29	1	19	11	3	100	40	11	5
11. Photographers, Musicians, &c.	46	—	26	20	8	90	40	18	11
	—	41	2	39	2	60	30	23	11
11a. Showmen	3	—	0	3	2	80	40	2	2
12. Merchants	9	—	9	0	0	—	—	—	—
13. Brokers, &c.	84	2	71	15	5	120	30	18	7
14. Travellers	88	2	38	52	15	100	30	50	22
15. Officials	2	—	2	0	0	—	—	—	—
16. Clerks	401	—	93	308	24	78	10	240	36
	—	82	1	81	0	45	10	36	8
17. Bankers	43	—	19	24	1	89	5	21	1
18. Insurance clerks	26	—	12	14	2	87	5	12	2
19. Insurance agents	42	—	23	19	5	100	30	19	8
20. Farmers:									
Great Britain	249	29	20	258	5	70	30	202	77
Ireland	328	71	3	396	1	30	15	119	59
21. Agricultural employers	10	—	5	5	3	90	40	5	3
22. Merchant service	40	—	10	30	3	100	30	30	10
23. Railways	87	—	9	78	2	82	5	64	4
24. Telephones	18	—	4	14	2	70	20	9	3
	—	12	0	12	0	50	10	6	1
25. Other employers	271	30	208	93	60	110	40	102	76
26. Ditto, own account	315	—	0	315	0	80	20	252	63
	—	306	0	306	0	40	20	122	61
27. Dealers	17	—	17	0	0	—	—	—	—
Shopkeepers: Employers	169	25	80	114	30	110	40	125	46
28. Ditto, own account	271	125	0	396	0	90	50	356	198
29. Ditto, Assistants	638	252	10	880	5	65	15	578	132
30. Costermongers, &c.	58	20	0	78	0	65	15	51	12
31. Sweeps	7	—	0	7	0	70	30	5	0
Total and Results‡	3,668†	1,255	900*	4,023	75	71	—	2,847†	294†

* There should be added some numbers to allow for the income-tax paying officers afloat or abroad in 1901, perhaps 10,000 to 15,000 for the Army and Navy jointly.

† Viz., £284,700,000 ± £29,400,000.

‡ The moduli are compounded by adding squares and taking the square root of the sum. $(100K)^2 = c^2s^2 + n^2k^2$.

It remains to compute the error in the total from the errors in the details. Let n stand for the number of non-taxpayers in each class, c for its modulus—given in thousands—s for the average income in £, and k for its modulus. c and k are to have the meaning discussed above and to be regarded as measuring that particular distance from the average known as the modulus in mathematical statistics.

Let A_1 be the estimate and A the true measurement, and let $A_1 = A\,(1+e)$.

Let A^1 be the measurement if A_1 was in defect equal to the modulus in both its factors, so that $A^1 = A_1 . \left(1+\frac{c}{n}\right)\left(1+\frac{k}{s}\right) = A_1\left(1+\frac{c}{n}+\frac{k}{s}\right)$ approximately. Then by the theory of error $e^2 = \left(\frac{c}{n}\right)^2 + \left(\frac{k}{s}\right)^2$ approximately,

$$\text{and } A_1 = A + \sqrt{[c^2s^2 + k^2n^2]} \text{ approximately} = A + K'.$$

Then K' is the modulus for the product.

In the table K is taken as $\frac{K'}{100}$, to correspond with the units used, and is worked out for each class and sub-class separately.

To get the modulus for the aggregate we have by a known principle to add the squares of the moduli of the items and take the square root of the sum. If C is this final modulus,

$$C^2 = \Sigma(K^2) = \Sigma(c^2s^2 + k^2n^2) = \Sigma(c^2s^2) + \Sigma(k^2n^2) = 6{,}300 + 80{,}000 = 86{,}300$$
$$\text{and } C = 294, \text{ viz. } 29{,}400{,}000l.$$

The first term is due to the margin (c) in numbers, the second to the margin (k) in income. The second term of itself would give C = 283; in fact, the errors in numbers are not important, and we need not therefore discuss the effect that our approximate knowledge of the total number in the group has on the accuracy of the result.

We thus arrive at the conclusion that the aggregate *earned* income in the intermediate group is 285,000,000*l.*, with modulus 30,000,000*l.*, using round numbers. This is subject to the definitions and limitations of the income dealt with as stated throughout the Report, and is conditioned by the accuracy of the occupational returns in the census.

If Classes 20, 25, 26, 27, 28, and 29 are excluded, the margin in the aggregate of the remaining classes is small; the result for Classes 1 to 19, 21 to 24, 30, 31 being—

No. of persons 1,263,000, modulus 33,000; aggregate income, 108,700,000*l.*, modulus 5,700,000*l.*

UNEARNED INCOME.

Estimates for this can only be satisfactorily made by the authorities of Somerset House, but we have endeavoured to interpret the tables given in the Reports of the Income Tax Commissioners.[1] It appears that 45,000,000*l.* under Schedules A, C, and D is 'unearned' income belonging to persons with less than 160*l.* a year from all sources. Of this the tax on 18,000,000*l.* is collected from and repaid to about

[1] We have had access to some details not published in the reports, which have enabled us to split up the tables; but the estimates based on them are not authoritative.

Distribution and Average of Incomes under 160*l*.

—	Men and Lads. Percentages. 40*l*. or under	Over 40*l*. and not over 60*l*.	Over 60*l*. and not over 80*l*.	Over 80*l*. and not over 100*l*.	Over 100*l*. and not over 120*l*.	Over 120*l*. and not over 140*l*.	Over 140*l*. and not over 160*l*.	Average	Women and Girls. Percentages. 40*l*. or under	Over 40*l*. and not over 60*l*.	Over 60*l*. and not over 80*l*.	Over 80*l*. and not over 100*l*.	Over 100*l*. and not over 120*l*.	Over 120*l*. and not over 140*l*.	Over 140*l*. and not over 160*l*.	Average	Weights. Men and Lads	Women and Girls
Teachers:																		
14 Counties, England and Wales	13	6	13	12	22	22	12	£ 96	32	35	12	15	5	1	—	£ 55	4	10
41 Boroughs, England and Wales	13	5	9	16	18	17	22	102	11	21	23	23	13	6	3	76	4	10
Scottish Burghs	2	2	4	16	25	24	28	130	3	4	22	32	24	12	3	102	1	1
Bankers	14	13	13	14	14	14	18	90	—	—	—	—	—	—	—	—	4	—
Insurance	21	18	12	12	15	10	12	85	13	31	46	7	3	—	—	61	2	1
Railways	10	13	26	22	15	8	6	80	—	—	—	—	—	—	—	—	8	—
Other Commercial and Industrial Clerks	18	13	21	19	14	8	7	80	51	32	11	3	2	1	—	About 40	35	7
Local Government:																		
London	0	1	1	17	28	23	30	120	0	7	26	54	7	3	3	86	1	1
30 English and Welsh Boroughs	13	9	16	18	19	13	12	91	53	26	9	5	3	3	1	About 48	1	1
7 Scotch Burghs	9	8	13	17	24	15	14	93	37	32	22	3	3	1	2	50	1	—
Central Government:																		
England and Wales	8	14	14	17	17	17	13	95	27	29	26	10	4	3	1	60	5	2
Scotland	8	15	15	23	17	16	6	90	—	—	—	—	—	—	—	—	1	—
Ireland	10	13	16	21	18	14	8	89	—	—	—	—	—	—	—	—	1	—
	14	12	18	18	16	12	10	87	28	28	18	15	7	3	1	61	—	—

340,000 persons and the tax on the remaining 27,000,000*l*. is exempted and not paid; this last sum not improbably belongs to about 300,000 persons. Whatever the numbers of persons, we have here the sum of 45,000,000*l*. accruing as unearned incomes to persons, occupied or unoccupied, who have less than 160*l*. a year. In addition, there is a relatively small sum of interests, pensions, &c., which does not come under the cognisance of the Department, which has been estimated as not more than 5,000,000*l*. An unknown part of these sums, however, belongs to the wage-earning class.

Putting these estimates in conjunction with our last, and increasing the modulus to allow for the additional uncertainty, we reach the conclusion that *the intermediate group contains* 4,000,000 *to* 4,100,000 *persons, with an aggregate income, together with a relatively small amount of 'unearned' income belonging to the wage-earners, from all sources between* 300,000,000*l*. *and* 370,000,000*l*. *a year*. The most probable estimate is 335,000,000*l*., and (subject to the definitions we have used) it is distinctly improbable that the aggregate is outside the limits stated.

Distribution of Income by Amount.

It is not possible to distribute the four million persons in our intermediate class according to their incomes, for it is only in Classes 1, 2, 9, 16, 17, 18, and 23 that we have any information, and these between them only amount to 19 per cent. of the whole. The table on page 197 shows the distribution for these various groups and the weighted result when the groups receive importance according to their numbers. There is nothing improbable in the distribution shown, the large percentage under 40*l*. shows that we have included an adequate number of boys and girls.

Recommendations.

The work would be more definite if the Labour Department, working results of the census of 1911. It is greatly to be desired that the Irish census should be harmonised with that of England and Wales in its sub-divisions, and that the distinction between makers and dealers and between employers, employed, and those working on their own account should be made.

For the whole of the United Kingdom it would be a great improvement if clerks were given, in an additional tabulation, according to the main occupations to which they were attached, and if wholesale dealers were separated from shopkeepers.

The work would be more definite if the Labour Department, working with the Census Office, published an estimate of the number of persons who might be considered as manual workers, heading by heading from the census.

The Inland Revenue Commissioners have a great deal of information unpublished and possibly untabulated. The Fifty-third Report has unfortunately not repeated the important table on p. 138 of the Fifty-second showing the *amount* of income taxed at 9*d*.; as to the *numbers*,

we find still only the statement in a footnote that the 9*d*. rate was allowed to approximately three-quarters of a million persons annually. It is greatly to be desired that the Commissioners should publish detailed information showing the total number of persons who pay the lower rate, the numbers in relation to the amount of earned income, and the numbers in relation to the amount of income whether earned or unearned.

Gaseous Explosions.—Third Report of the Committee, consisting of Sir W. H. PREECE (*Chairman*), Mr. DUGALD CLERK *and* Professor BERTRAM HOPKINSON (*Joint Secretaries*), Professors BONE, BURSTALL, CALLENDAR, COKER, DALBY, *and* DIXON, Dr. GLAZEBROOK, Professors PETAVEL, SMITHELLS, *and* WATSON, Dr. HARKER, Lieut.-Colonel HOLDEN, Captain SANKEY, Mr. D. L. CHAPMAN, *and* Mr. H. E. WIMPERIS,[1] *appointed for the Investigation of Gaseous Explosions, with special reference to Temperature.*

SIX meetings of the Committee have been held, one each at the Universities of Leeds, Manchester, and Cambridge, one at the Imperial College of Science and Technology, and two at 57 Lincoln's Inn Fields, by the kindness of Mr. Dugald Clerk. In accordance with previous practice, notes dealing with their current work have been presented for discussion by members of the Committee, as follows:—

No. 14.	Dissociation	A. Smithells and W. A. Bone.
No. 15.	Ignition Temperatures of Gases	H. B. Dixon.
No. 16.	Modern Theories of Gases	Sir W. H. Preece.
No. 17.	Radiation from Flames	H. L. Callendar.
No. 18.	Radiation in a Gaseous Explosion	B. Hopkinson.

During the Session 1909-10 the experimental work by members of the Committee, to which allusion was made in the Second Report (1909), has been continued. Mr. Dugald Clerk's measurements of the volumetric heats of air and CO_2 at ordinary temperatures by the method of adiabatic compression have yielded results in close accordance with those obtained by Swann. The method of division of heat-loss employed by Mr. Clerk in reducing the results was the same as that which he used in his original high temperature experiments. The correctness of the results obtained at the lower temperatures by this method goes far to justify its application to the compression and expansion of highly-heated gas. An account of these experiments will shortly be published, and will be quickly followed, it is hoped, by an account of further work on the compression of flame and heated gases on which Mr. Clerk is already engaged. Professor Hopkinson has published a

[1] Mr. Wimperis joined the Committee after the completion of the Report.

paper on the radiation in a gaseous explosion, to which more particular reference is made later in this Report.

A series of experiments on the temperatures of ignition of hydrogen and oxygen produced by adiabatic compression (according to the suggestion of Professor Nernst) has been carried out by Professor H. B. Dixon. It was found necessary to check the descent of the piston mechanically when the 'ignition point' was reached, instead of allowing the flame itself to stop the movement, as in Falk's experiments.[1] With quickly-igniting mixtures, such as electrolytic gas, there is little difference between the results obtained with a freely moving and with a checked piston; but with slowly igniting mixtures, such as mixtures of hydrogen and air and mixtures with a large excess of oxygen or of hydrogen, there is a considerable difference between the two methods. Thus, while the compression necessary to fire electrolytic gas agrees closely with that found by Falk, the addition of oxygen was found to lower the ignition-point continuously so far as the experiments were carried. Using the value of γ deduced from Joly's experiments, Professor Dixon finds that the ignition-point of electrolytic gas is 557° C., which is in close agreement with the ignition temperature determined by Dixon and Coward last year.

Professor Dalby is communicating to the Association an account of his measurements by means of an orifice of the air-supply to a gas-engine. This work, while not bearing directly on the matters under discussion by the Committee, will be of considerable assistance to those who have to experiment on gas-engines and desire to determine the proportion of air in the charge. Professor Coker has made, and will shortly publish, further measurements of the temperatures in a gas-engine cylinder. The Committee hope to be able to discuss Professor Coker's experiments at greater length next year.

The Committee are not aware of any important publications on the Continent or in America (during the past year) which bear directly on their work, though mention should be made of a valuable paper by Hans Schmidt[2] dealing with the radiation from a Bunsen flame.

On the Radiation from Gases.

In the first and second Reports of the Committee reference was made to the part played by radiation in the cooling of the products of an explosion, and to its bearing on the measurements of volumetric and specific heat with which those Reports were principally concerned. The general question of radiation from heated gases has, however, from the point of view of the Committee, an interest and importance of its own which are sufficient to justify a detailed study of it in its wider aspects. Radiation plays a part comparable with that of conduction in determining the heat-flow from the gas to the cylinder walls in the gas-engine, and it is this flow of heat which is the most important peculiarity of the gas-engine, and to which are chiefly due the leading

[1] 'The Ignition Temperatures of Hydrogen-Oxygen Mixtures,' K. G. Falk [*Journ. American Chem. Soc.*, vol. xxviii., No. 2, 1906.] 'The Ignition Temperatures of Gaseous Mixtures,' K. G. Falk [*Journ. American Chem. Soc.*, vol. xxix., No. 2, 1907].

[2] *Ber. der Deutschen Phys. Ges.*, 1909, p. 87.

characteristics of its design. Even to the uninstructed eye the most obvious features about large internal-combustion engines are the arrangements for cooling, and the great size and weight for a given power which is necessitated mainly by those arrangements. The difficulties which the designer has to meet are due in the main to the stresses set up by the temperature gradients which are necessary to sustain the flow of heat. In the present state of the art it is probable that the most important service which science could render to the gas-engine constructor would be to establish definitely the principles upon which depends the heat-flow from hot gases into cold metal with which they are in contact, and thus to enable him to predict the effect upon heat-flow of changes in the temperature, density, or composition of the charge, and in the state of the cylinder walls.

The Committee do not propose in this report to deal with the whole of this large question, but will confine their attention to one important factor in heat-flow, namely radiation. The subject is a wide one, which has excited much attention among physicists and chemists, and on several important points agreement has not yet been reached. No attempt will, therefore, be made to do more than state shortly the experimental facts, and to define the issues which have been raised in regard to the explanation of these facts.

Practical Effects of Radiation.

It is believed that the first instance in which radiation from a flame was used in an industrial process, with knowledge of its importance, was the re-generative glass furnace of Frederick Siemens, which he described at the Iron and Steel Institute in 1884. Here the combustible gas was burnt in a separate chamber and the hot products of combustion were led into the furnace. The objects to be heated were placed on the floor of the furnace out of contact with the stream of flame which flowed above them. They would therefore receive heat only by radiation, and it was supposed that this radiation came in a large measure from the flame. Siemens, however, was of opinion (in 1884) that the radiation was due to incandescent particles of carbon, and that there was little radiation from a non-luminous flame.[1]

In 1890 Robert von Helmholtz measured the radiation from a non-luminous coal-gas flame 6 mm. diameter, and found it to be about 5 per cent. of the heat of combustion.[2] The radiation from a luminous flame was greater, but not very much greater—rising to a maximum of 11½ per cent. for an ethylene flame. Discussing the Siemens furnace in the light of these results, R. von Helmholtz calculated that radiation from the flame in the furnace could only account for a small fraction of the actual heat transmission. He pointed out, however, that a large flame would probably radiate energy at a greater rate than a small one. But while admitting that for this reason gaseous radiation

[1] Captain Sankey has prepared an abstract of papers relating to the Siemens' furnaces. See Appendix C, p. 225.

[2] *Die Licht- und Wärmestrahlung verbrennender Gase*, Robert von Helmholtz, Berlin, 1890.

might play a part in the heat transmission, he suggested that a more important agent was radiation from the roof of the furnace which received heat by direct contact with the hot gas and so reached a very high temperature. He showed by calculation that a comparatively small excess of temperature in the roof over that of the floor would cause a sufficient flow of heat.

But though the discussions on the Siemens furnace and the work of Helmholtz show that the idea that a flame, even if non-luminous, might radiate large amounts of heat was a familiar one to many people twenty years ago, its possible importance in causing loss of heat during and after a gaseous explosion and in determining the heat flow in a gas-engine does not appear to have been appreciated until quite recently. Professor Callendar was probably the first to draw attention to its significance in this connection. In the discussion on a paper about explosions, read before the Royal Society in 1906, he said that he had found a non-luminous Bunsen flame to radiate 15 to 20 per cent. of its heat of combustion, and expressed the opinion that the loss from this cause in a closed-vessel explosion would be of the same order.[1] Professor Callendar's note dealing with this matter is published in full in Appendix A, and it is only necessary to state here that he was led to study the subject by his work on the efficiency of the petrol motor.

There are, in fact, several points about the behaviour of gas-engines which suggest the importance of radiation as a cooling agent. The particular matter which attracted Callendar's attention was the effect of speed on thermal efficiency. His experiments showed that a part of the loss of efficiency in an internal-combustion motor, as compared with the corresponding air-cycle, was independent of the speed at which the engine was run. The loss of heat per cycle could, to a first approximation, be represented by an expression of the type $A + \frac{B}{n}$ where n is the number of revolutions per minute and A and B are constants. The term A represents a constant loss of heat per explosion, and among the many causes contributing to this constant loss of heat, radiation from the flame is probably important.[2]

Another phenomenon which is difficult to explain, except as the result of radiation, is the effect of strength of mixture on heat-loss. The following table shows some results which were obtained by Hopkinson upon a 40-h.p. gas-engine[3]:—

Percentage of gas in cylinder contents	8·5	11·0 per cent.
Total heat-loss per minute	1,510	2,300 B.Th.U.
Total heat-loss as percentage of total heat-supply .	29	34 per cent.
Temperature of piston	300° C.	430° C.

It will be observed that the proportion of heat-loss to the walls increases very materially as the strength of mixture is increased. If the transfer of heat were wholly due to conduction it might be expected,

[1] Hopkinson, *Proc. Roy. Soc. A.*, vol. lxxvii., p. 400.
[2] *Proc. Inst. Automobile Eng.*, June 1907.
[3] *Proc. Inst. C.E.*, vol. clxxvii. (1909).

apart from the disturbing influence of speed of ignition, which in this case was not very important, that the percentage of heat-loss would rather diminish with increase of charge, because the temperature with the stronger mixture should be relatively less on account of the increase of volumetric heat. The increased temperature of piston and valves would work in the same direction. The existence of radiation, however, which increases more rapidly in proportion to the temperature, would account for the increased heat-flow. The practical importance of questions of this kind is also illustrated by these figures, from which it appears that the piston is 50 per cent. hotter, though the charge of gas is only increased 30 per cent.

More direct evidence of the importance of radiation is furnished by experiments on the effect of the surface of the walls. In the second report of the Committee reference was made to the belief which is widely spread among those who are concerned with the practical design and operation of gas-engines that polishing the interior of the combustion chamber tends to increase efficiency. Some experiments were also quoted in which it was found that lining an explosion vessel with bright tinfoil perceptibly retarded the cooling of the products. More recently an explosion vessel has been plated with silver on the inner surface, and the results have been compared after exploding identical mixtures, first when the lining was polished, and second when it was blackened over with lamp-black. It was found that by highly polishing the interior of the vessel the maximum pressure reached could be increased 3 per cent. and the subsequent rate of cooling during its earlier stages reduced by about one-third. These experiments leave no doubt of the reality and of the practical importance of radiation as a factor in determining the heat-loss in the gas-engine.[1]

Reference may also be made to the part played by radiation in determining the heat-flow in a boiler. Attention was drawn to this by Dalby in a recent report to the Institution of Mechanical Engineers.[2] The circumstances in this case are widely different from those usually obtaining in the gas-engine, but the instance serves to emphasize the importance to the engineer of the questions which will be discussed in this report.

Amount of the Radiation from Flame.

R. von Helmholtz appears to have been the first to attempt the accurate measurement of the radiation emitted by a flame. He found that a 'solid' flame 6 mm. diameter, burning coal-gas, radiated about 5 per cent. of the total heat of combustion. A carbon monoxide flame radiated about 8 per cent., and a hydrogen flame about 3 per cent. On account of the smallness of the flame his experiments have not much application to the problem of the gas-engine. The size of the flame affects the matter in two ways. In the first place, a large flame radiates more per unit of area than a small one, because a flame is to a great extent transparent even to its own radiation, so that radiation is received not only from molecules at the surface of the flame, but also

[1] Hopkinson, *Proc. Roy. Soc. A.*, vol. lxxxiv. (1910), p. 155.
[2] *Proc. Inst. Mech. Eng.*, October 1909.

from those at a depth within it. This matter will be further dealt with in another section of the report. The second point is that the cooling of the gas is slower in a large flame than in a small one. The radiation originates in the vibration of the CO_2 and steam molecules, and the life of one of these molecules as a radiating body extends from the moment of its formation to the time when its vibrational energy has been destroyed by radiation and by collision with colder molecules, such as those of the air surrounding the flame. The smaller the flame the more rapid will be the extinction of the vibrations, and the less, therefore, the total amount of radiation per molecule. The products of explosion in a closed vessel or in a gas-engine differ considerably in this respect from any open flame, however large, which it is possible to produce, for they are not subject to cooling by mixture with the outside air. Moreover, the density of the gas is very much greater.

Callendar has repeated some of Helmholtz's experiments on a larger scale, and has found that the radiation in a non-luminous coal-gas flame 30 mm. in diameter may amount to 15 per cent. of the whole heat of combustion. Further reference will be made to Callendar's work under the heading of 'transparency.'

Hopkinson has recently made measurements of the radiation emitted in the course of an explosion in a closed vessel and in the subsequent cooling. A bolometer made of blackened platinum strip was placed outside a window of fluorite in the walls of the explosion vessel. The electrical resistance of this bolometer was recorded by means of a reflecting galvanometer throwing a spot of light on a revolving drum, and an optical indicator traced simultaneously a record of the pressure on the same drum. He found that the total heat radiated during and after an explosion of a 15 per cent. mixture of coal-gas and air amounted to over 22 per cent. of the whole heat of combustion. The radiation which had been received at the moment of maximum pressure amounted to 3 per cent., and it continued, though at a diminishing rate, for a long period. Radiation was still perceptible half a second after maximum pressure, when the gas-temperature had fallen to 1000° C.[1]

Nature and Origin of the Radiation from Flames.

In the gas-engine cylinder and in explosion experiments we are usually concerned with flames in which there is some excess of air. A mixture of similar composition burnt at atmospheric pressure would give an almost non-luminous flame; in the gas-engine there is more luminosity on account of the greater density. There is, however, no reason to suppose that the radiation in the gas-engine cylinder differs materially as regards its quality or origin from that emitted by an open flame.

A very complete analysis of the radiation from different kinds of flame was made by Julius, and his experiments leave no doubt that the radiation is almost wholly due to the CO_2 and steam molecules. He

[1] *Proc. Roy. Soc. A.*, vol. lxxxiv. (1910), p. 155. See also Appendix B to this Report (p. 221).

examined the spectrum of the flame by means of a rock salt prism, and he found that in all flames producing both CO_2 and steam most of the radiation was concentrated into two bands, the wave lengths of which are, respectively, $4{\cdot}4\,\mu$ and $2{\cdot}8\,\mu$. In a pure hydrogen flame the 4·4 band disappears completely, but the other remains; and in the pure CO flame the 2·8 band disappears, the other remaining. These results are independent of the nature of the combustible gas, the spectrum depending solely on the products of combustion.[1]

A confirmation of the statement that the radiation from these flames originates in the CO_2 and H_2O molecules only was furnished in the course of the work by R. von Helmholtz, to which reference has been made above. He measured the amount of radiation per litre of gas consumed, emitted by flames of given size burning respectively hydrogen, carbon monoxide, and certain compound gases, such as methane, giving both CO_2 and steam. The supply of air was adjusted in each case so that the flame was just non-luminous. His results are best given in his own words, but it should be stated that he worked with a small flame about 6 mm. diameter and measured the radiation with a bolometer, taking the steady change of its resistance as a measure of the amount of radiation falling upon it:—

'According to the experiments of Julius described in the first chapter, the *quality* of the radiation of flames depends only on the nature of the burnt and not on that of the burning gases. It is relevant to inquire whether the *quantity* of radiation is also dependent on the mass of the products of combustion. I have calculated in the second and third columns below how many litres of H_2O and CO_2, respectively, arise theoretically from each litre of combustible gas. I then assume that for every litre of water produced as much radiation is sent out as corresponds to the radiating power of a hydrogen flame—for this gas yields one litre of H_2O per litre of combustible—and that in a corresponding way the radiation from one litre of carbonic acid would be determined by the radiating power of the carbonic oxide flame, and I can then calculate the radiation from the non-luminous flames of methane, ethylene, and coal-gas.

Gas	Litres		F	
	H_2O	CO_2	Observed	Calculated
Hydrogen	1	0	74	—
Carbon Monoxide	0	1	177	—
Marsh gas	2	1	327	325
Ethylene	2	2	510	502
Coal gas	1·2	0·5	181	179

'The correspondence between the calculated numbers with the radiation from a flame which has just been rendered non-luminous surprised me the more since the latter is conditioned, in some measure,

[1] *Die Licht- und Wärmestrahlung verbrannter Gase.* Dr. W. H. Julius, Berlin, 1890.

by the volume of air mixed with the gas, and this is very different for the three non-luminous flames. On this account it cannot be asserted that this agreement is not accidental. Moreover, the number of observations is much too small. Nevertheless, the experiment seems worthy of record and will be followed up further.'

With regard to the last remarks, it is to be noted that the fact that the flame was just rendered non-luminous shows that the air was in each case in approximately the proportion required for complete combustion. The heating value of such a mixture is much the same for all the gases in the above table, and the temperatures of the flames would be still more nearly the same, the higher heating value of a CO mixture being partly neutralised by the high specific heat of the products. The agreement is certainly more than a coincidence. W. T. David, from a comparison of the radiation emitted in the steam and CO bands respectively in a coal-gas and air explosion, infers that CO_2 radiates about $2\frac{1}{2}$ times as much as steam per unit of volume. This result, which was obtained in ignorance of Helmholtz's estimate, agrees with it almost exactly.

Cold CO_2 shows a strong absorption band at the same point of the spectrum as the emission band given by a flame in which CO_2 is produced, and water-vapour powerfully absorbs the radiation from a hydrogen flame.

As stated above, it is most probable that the radiation in an explosion also consists almost entirely of the same two bands as are emitted by the Bunsen flame. A complete analysis of the radiation from an explosion has not been made, but Hopkinson and David found, using a recording bolometer, that the radiation is almost completely stopped by a water-cell, and that it is largely stopped by a glass plate. It follows that the luminosity of the flame in an explosion or in a gas-engine accounts for but little of the energy which it radiates.

Molecular Theory of Radiation from Gases.

Much difference of opinion exists as to the physical interpretation of the facts described in the preceding sections. The issues in this controversy can conveniently be stated in terms of the molecular theory, and it is, therefore, desirable to give a short account of this theory. But it will be apparent that the issues are not merely of theoretical interest, but are in large measure issues of fact capable of being tested by experiment, and that the answers to important practical questions may depend on the manner in which they are settled.

According to the kinetic theory, the energy of a gas must be referred partly to translational motion of the molecules as a whole and partly to motions of some sort internal to the molecules. The translational motion is that which causes the pressure of the gas, and in the case of gases for which $\frac{pv}{\theta}$ is constant (with which alone we are concerned in this discussion), the translational energy per unit of volume is equal in absolute measure to $1\frac{1}{2}$ time the pressure. This part of the energy may conveniently be called 'pressure energy.' It

amounts to nearly 3 calories per gramme molecule, or to 12 foot-pounds per cubic foot per degree Centigrade.

The other part of the energy produces no external physical effect except radiation, and at ordinary temperatures, when there is no radiation, its existence and amount are inferred from the fact that when work is done or heat put into the gas the corresponding increase in pressure energy amounts to only a fraction of the whole. The internal motions to which this suppressed energy corresponds may be pictured as of a mechanical nature, such as the vibrations of spring-connected masses or as rotation about the centre of gravity of the molecule, but there is not the same reason as exists in the case of the transitional energy for supposing that they are really of this character. They may be, and indeed probably are, electrical phenomena, at any rate in part. Any radiation from the gas must take its origin in this internal motion, and so much of that motion as gives rise to radiation must be of a periodic character and have a frequency equal to that of the radiation emitted. It will be convenient to call the whole energy which is internal to the molecule 'atomic energy,' and that part of it which gives rise to radiation may be called 'vibrational energy.' The vibrational energy may be imagined as due to high-frequency vibrations within the molecule, and the rest of the atomic energy as due to slower movements—perhaps rotations of the molecule as a whole—which do not produce any disturbance in the æther. This remaining energy may conveniently be called 'rotational,' it being understood that the motion to which it corresponds is not necessarily a physical rotation, but is some internal motion which gives no external physical effects.

When the gas is in a steady state the various kinds of energy will bear definite ratios to one another, dependent on the temperature and pressure. It may be expected, however, that after any sudden change of temperature or pressure the gas will not at once reach the steady state of equilibrium corresponding to the new conditions. For instance, it may be that in the rapid compression of a gas the work done goes at first mainly to increasing the translational energy. If in such case the compression be arrested, and if there be no loss of heat, this form of energy will be found in excess; and a certain time, though possibly a very short time, will elapse before the excess is transformed by collisions into atomic energy and the state of equilibrium attained. This change would be manifest as a fall of temperature or of pressure without any change of energy.

If, on the other hand, the gas be heated by combustion, the first effect is undoubtedly an increase in the energy of those molecules, and of those only which have been formed as the result of the combustion; and it is probable that in the first instance the energy of the newly formed molecules is mainly in the atomic form. Before equilibrium can be attained there must be a process of adjustment, in the course of which the energy of the new molecules will be shared with inert molecules, *e.g.*, the nitrogen in an air-gas explosion, while the translational form of energy will increase at the expense of the atomic energy. The final state of equilibrium reached will be the same at the same temperature, whether the gas was heated in the first

instance by combustion or by compression; the assumption that this is the case is involved in any statement of volumetric heat as a definite physical quantity. The pressure energy in the final state of equilibrium is certainly shared equally between the different kinds of molecules, but the atomic energy is not necessarily equally shared. It is known, for example, that the steam molecules, after an explosion of hydrogen and air, carry, on the average, more energy than the nitrogen molecules, though the pressure energy is the same.

The process of attaining equilibrium after an explosion, which has just been described, would (if heat loss were arrested) result in a rise of temperature, and in the ordinary case of rapid cooling it would retard the cooling. It would, therefore, be indistinguishable as regards pressure or temperature effects from continued combustion or after-burning.

Stated in terms of the molecular theory, the first question as to which there is difference of opinion is whether the radiation from a flame arises from gas which is in equilibrium or whether it comes from molecules which still possess a larger share than they will ultimately (in the equilibrium state) be entitled to, of the atomic energy which resulted from their formation. If the products of combustion of a non-luminous Bunsen flame were heated—say, by passing through a hot tube—to the average temperature of the flame, would they emit substantially the same amount of radiation? In order to clear the ground for the discussion of this question it will be convenient, first, to state two or three points about which there will probably be general agreement. First, there is here no question of the origin of luminosity, for the luminous part of the radiation from the flame possesses practically no energy. Secondly, the radiation, whether in the heated gas or in the flame, arises almost entirely from the compound constituents CO_2 and H_2O; in neither case does any come from the molecules of nitrogen or of excess oxygen. And, thirdly, the powerful absorption of cold CO_2 for the radiation from a CO flame, and of water vapour for that from a hydrogen flame, will probably lead all to admit that these gases when heated will emit *some* radiation of the same type. The only question is, how much?

R. von Helmholtz was of opinion that the radiation in a flame comes mainly from molecules which have just been formed, and which are therefore still in a state of vigorous vibration. Pringsheim, Smithells, and others take the same view. This is practically equivalent to saying that this radiation, like the radiation of higher frequency which gives luminosity, is due to chemical action and not to purely thermal causes. On the other hand, Paschen and some others have maintained that the radiation from a flame is purely thermal, or that it arises from gas which has attained the normal or equilibrium state and is substantially the same as that which would be emitted if the products of combustion were heated.

It will readily be seen that the difference between the two opinions really turns on the question of the time taken by a gas which is not initially in, or has been disturbed from, the equilibrium state to attain that state. All will concede that the CO_2 or steam molecule will

radiate more powerfully just after its formation than at any other time. If, as R. von Helmholtz contended, the greater part of the radiation which it gives out in the course of its life is to be ascribed to this early period of its history, we must suppose that that period is sufficiently extended to give time for the emission of a considerable amount of energy, with a rate of radiation which, though greater than that of the gas in its ultimate equilibrium state, is at least of the same order of magnitude. In other words, we must suppose that the process which may indifferently be called attainment of equilibrium, or continued chemical action, must go on in the gases as they pass through the flame for a time of the order perhaps of $\frac{1}{10}$ of a second. For if it be supposed that equilibrium is reached in an excessively short time, say in $\frac{1}{1000}$ second or less, then the radiation, if ascribed to that short period, must be supposed to be of corresponding intensity—there must be a sudden and violent flow of energy by radiation just while combustion is going on, and very little radiation after it is complete. This is, however, negatived by the bolometer measurements made during an explosion, which show that radiation goes on for something like half a second after maximum pressure (see Appendix B). Those who hold that the radiation emitted by CO_2 and steam is mainly due to continued combustion must be prepared to admit that such combustion goes on for a long period after the attainment of maximum pressure in an explosion. The issue involved here is, in fact, the same as that in the controversy about 'after-burning.'

The principal argument advanced by R. von Helmholtz in support of his view is the experimental fact discovered by him that the radiation of a flame is diminished by heating the gas and air before they enter the burner, in spite of the fact that the temperature of the flame must be raised. This he explains by the acceleration of the approach to the state of equilibrium which would be brought about by the more frequent collisions between the newly formed compound molecules and their neighbours.

The question of the velocity with which a gas approaches its normal state after a disturbance has been much discussed in connection with the kinetic theory. Immediately after an explosion we have an extreme case of such a disturbance, the atomic energy being, at any point which the flame has just reached, in considerable excess. The transformation of this energy into the pressure form will proceed at a rate diminishing with the amount remaining to be transformed and, in the final stages of the process at all events, proportional thereto. The slowness of approach to the state of equilibrium may be measured by the time required for the reduction of the untransformed energy in any specified ratio. It is usual to take $\frac{1}{e}$ as this ratio, and following Maxwell, the corresponding time may be called the 'time or relaxation.' Estimates of this time, based on the kinetic theory of gases, may be made in various ways, but they all involve hypotheses as to the nature of the action between the molecules, and must be regarded as little more than speculation. It will be well, however, to indicate the general character of the arguments on which they are based. By methods

which need not be considered in detail here it is possible to calculate the number of collisions with its neighbours which the average molecule undergoes per second. This calculation can be approached in various ways, based on different kinds of data, but they all lead to the same result, at any rate as regards order of magnitude—namely, that a molecule of air at normal temperature and pressure collides on the average 3×10^9 times per second with other molecules. At every collision the energy distribution in the colliding molecules is modified, both as regards the manner in which it is shared between the two and the relative proportions due to vibration and translation in either. It is argued that after every molecule has suffered a few thousand collisions, which will happen in a millionth of a second, the gas must have reached a steady average state. This argument would, however, be upset if the interchange of energy as between vibration and translation at each collision were sufficiently small. It is only necessary to suppose that a vibrating molecule loses less than one thousand millionth part of its vibratory energy at each collision, to raise the time of relaxation to something of the order of a second. Any objection to this supposition must be founded on some hypothesis, which cannot be other than entirely speculative, as to the mechanism of a collision. The kinetic theory, therefore, can give no information about the absolute value of the time of relaxation, though it provides valuable suggestions as to the way in which that time is affected by the temperature and density of the gas.

There is plenty of physical evidence, however, that in ordinary circumstances the time of relaxation is excessively short. The phenomenon of the propagation of sound shows that compressions and rarefactions of atmospheric air may take place many thousands of times in a second without the gas departing appreciably at any instant from the state of equilibrium. The experiments of Tyndall, in which an intermittent beam of radiant energy directed through the gas caused variations of pressure sufficiently rapid to give sounds, show that the transformation of vibrational into pressure energy under the conditions of his experiments is a process far more rapid than any with which we are accustomed to deal in the gas-engine or in the study of gaseous explosions. The departure from equilibrium which follows combustion is, however, of a special kind, and it may be that the gas is slower in recovering from it than when the disturbance is that produced by the propagation of sound at ordinary temperatures.

Transparency.

The radiation from hot gas is complicated by the fact that the gas is to a considerable extent transparent to its own radiation. The radiation emitted, therefore, depends upon the thickness of the layer of gas, instead of being purely a surface phenomenon, as in the case of a solid body. This property, besides being of great physical interest, is important from the point of view of the Committee because upon it depends, or may depend, the relative magnitude of radiation losses in engines or explosion vessels of different sizes.

The transparency of flames is well illustrated by some experiments which Professor Callendar has been making, and which he showed to the Committee. The radiation from a Mêker burner (which gives a 'solid' flame without inner cone) was measured by means of a Fery pyrometer, the reading of which gives a measure of the radiation transmitted through a small cone intersecting the flame and having its vertex at this point of observation (see fig. 1). Callendar proposes to give the name 'intrinsic radiance' to the radiation of a flame measured in this way, divided by the solid angle of the cone. When a second similar flame was placed behind the first in the line of sight, it was found that the reading recorded by the pyrometer was considerably increased, but not doubled; the first flame appeared to be partly, but not completely,

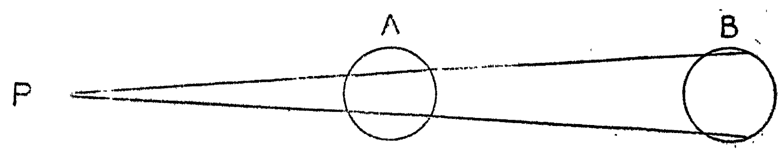


FIG. 1.

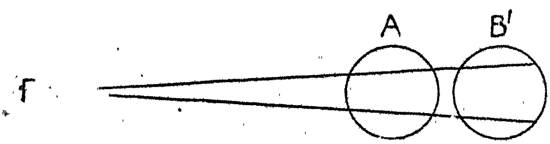


FIG. 2.

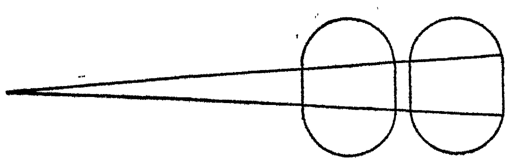


FIG. 3.

transparent to the radiation emitted by the second. A third flame placed behind the first two contributed a further but smaller addition to the radiation, and as the number of flames in the row was increased the radiation received from each fell off according to an exponential law. The total radiation from the whole row (which is that recorded on the pyrometer) tends to a finite limit as the number of flames is increased. The radiation from a depth of 12 cm. is about half, and that from a depth of 100 cm. is within one-half per cent. of that emitted by an infinitely great depth.

The general result of Callendar's experiments is to show that flames of a diameter of three centimetres or less burning at atmospheric pressure emit radiation approximately in proportion to the volume. If the diameter be increased beyond that figure the radiation will also increase,

but not in proportion to the volume of the flame. The radiation from very large flames would tend to become proportional to the surface, but no certain inference as to the diameter of flame for which this would be substantially true can be drawn from Callendar's experiments, because he was looking along a thin row of flames in which there was but little lateral extension.

The flames met with in a gas-engine cylinder or in explosion vessels differ from open flames such as can readily be produced in the laboratory, both in respect of the lateral extension which has just been mentioned, and also in respect of density. In both these particulars the difference is rather great, the least dimension of the mass of flame in a gas-engine cylinder being only in the smallest sizes comparable with the diameter of the Mêker burner flame, while the density of the gas just after firing in the gas-engine is from twenty to thirty times that of the burner flame gases. It does not seem possible from theoretical considerations to determine the effect of these two factors with sufficient accuracy to enable any quantitative inference as to radiation in the gas-engine to be drawn from laboratory experiments on flames, but it is useful to discuss their probable qualitative effects.

In fig. 1, P is the point of observation at which the pyrometer is placed, as in Callendar's experiments, and the portion of the flame from which the radiation is measured is that intercepted by the small cone. If a second similar flame B is placed behind A at a considerable distance but so that it is intersected by the cone, then the radiation recorded by the pyrometer will be increased, say, by 50 per cent., showing that of the radiation emitted by B and falling on A 50 per cent. is absorbed and the remainder is transmitted to the pyrometer. The absorbed energy is of course not lost, but must result in slightly increased radiation from A in all directions. The flame A appears to be a little hotter because of the proximity of B. Thus the increase of radiation absorbed at the pyrometer is due not only to the radiation transmitted from B but also to an increase in the intrinsic radiance of A. If the two flames are a considerable distance apart, the latter part is negligibly small, since the flame A does not then receive much radiation from B, and what it does receive is dissipated in every direction. But when flame B is pushed close up to A in to the position of B′ (fig. 2) this effect may be considerable, and it is obvious that it will be greatly enhanced if the two flames are extended laterally as in fig. 3. For in such case flame A must get rid of the energy which it is receiving by radiation from B′ mainly by an enhanced radiation in the direction of P. It may, therefore, be expected that the effect of lateral extension will be to make the flame apparently more transparent.

To a first approximation it may be expected that the radiating and absorptive powers of a gas at a given temperature will be proportional to its density. That is to say, two geometrically similar masses of flame, in which the temperatures at corresponding points are the same, and the densities in inverse proportion to the volumes (so that the total masses are the same), will radiate in the same way and to the same total amount. It would seem that this must be so, so long as the vibrations of the radiating molecules are the same in character and

amplitude in the two cases. For there will then be the same number of molecules vibrating in exactly the same way and arranged in the same way, in the two cases. The only difference is in the scale of the arrangement, and this can only affect the matter if the distance between molecules is comparable with the wave-lengths of the radiation emitted, which is not the case. It is only, however, within moderate limits that the molecular vibrations are independent of density. Angström found that the absorption of the radiation from a given source in a tube of CO_2 at ordinary temperature and atmospheric pressure was reduced by increasing the length and diminishing the pressure[1] in the same proportion so as to keep the mass of gas constant. Schäfer found that on increasing the pressure the absorption bands of this gas were widened, so that the curve connecting intensity of radiation and wave-length did not remain of the same shape.[2] These experiments were made at low temperatures, and at the higher temperatures in which the Committee are more particularly interested there has been but little work. There is no reason to doubt, however, that the character and amount of the radiation from CO_2 and steam at high temperatures will change with the density.

From the point of view of the molecular theory, such a change might be anticipated from either of two causes. An increase of density implies a proportionate increase in the frequency of molecular collisions, and this would result in greater facility of interchange between the translational and atomic types of energy. It is possible that the equilibrium proportion of the two types might be different in consequence. The denser gas may conceivably possess, with a given amount of translational energy, more atomic energy, and therefore radiate more strongly at a given temperature. It is certain that there would be a more rapid attainment of equilibrium in the gas after an explosion, or a rapid expansion. Another possible cause is a direct inter-action between the molecules apart from collisions. Two molecules at a sufficient distance apart will vibrate practically independently, each behaving as though the other was not there, except that there will be a tendency for them to vibrate in the same phase. But if the two are close together they react on each other so that the natural period or periods of the two together will not be the same as those which each would have if it were isolated.

Such direct measurements as have been made of the radiation after a closed vessel explosion suggest that the flame is more transparent than might be inferred from the experiments on open flames. According to information given to the Committee by Professor Hopkinson, W. T. David has found that the radiation received by a bolometer placed outside a fluorite window in the cover of a cylindrical explosion vessel 30 cm. × 30 cm. is greatly increased by highly polishing that portion of the opposite cover which can be 'seen' by the bolometer. This implies that a thickness of 30 cm. of flame in these circumstances can transmit much of the radiation which it emits. The density of

[1] *Ark. for Mat. Astron. och Fysik*, Stockholm, vol. iv., No. 30, p. 1.
[2] *Ann. der Physik*, vol. xvi. (1905), p. 93.

the gas in this case was atmospheric, and the 30 cm. thickness in the explosion vessel would be equivalent to perhaps 150 cm. of open flame if absorption were simply proportional to density. According to Callendar's experiment, such a thickness would be almost completely opaque. It is possible that the lateral extension is sufficient to account for this result. The open flame should be a cylindrical mass of dimensions 150 cm. × 150 cm., instead of a long strip with a cross section of 3 cm., in order to make the two cases strictly comparable. It will be remembered that in the discussion above it appeared that the laterally extended flame would seem to be more transparent.

In the course of the year Mr. D. L. Chapman, of Oxford, and Mr. H. E. Wimperis have joined the Committee.

The Committee recommend that they be reappointed, and ask for a grant of 100*l*.

APPENDIX A.

Radiation from Flames. *By* H. L. Callendar.

In the course of my experiments in 1903-04 with a small petrol motor of 2·36-inch bore on the variation of efficiency with speed, I became convinced that *the greater part* of the loss of efficiency with a small high-speed motor was practically independent of the speed. Loss by radiation from the flame appeared to be one among the many possible causes contributing to this result, and I accordingly made some experiments on radiation from flames with a view to estimate the probable order of magnitude and the possible limits of the loss incurred. The experiments were necessarily of a qualitative character, and could not be directly applied to the calculation of the actual loss occurring in an internal-combustion engine, but they appeared to indicate that the effect was much larger than had generally been supposed, and could not be neglected in a discussion of the heat loss occurring in a gaseous explosion.

Some of the results of these experiments were mentioned in the discussion on a paper by Professor B. Hopkinson, 'Explosions of Coal Gas and Air,'[1] and a general summary was given in the discussion on my paper, 'On the Effect of Size on the Thermal Efficiency of Motors,'[2] from which the following is a quotation.

'A large part of the energy of the flame during ignition exists in the form of energy of vibration of the dissociated and recombining ions, which is proved by the fact that a flame radiates energy more intensely than a mass of inert gas at the same temperature. The energy of vibration is realised as pressure, or energy of translation, only in proportion as the ions combine and equilibrium is established. The loss of thermal efficiency from this cause is merely another aspect of dissociation or increase of apparent specific heat, and is not a loss of heat at all, though it gives rise, as already explained, to a considerable diminution of the thermal efficiency. But while the condition of flame

[1] *Proc. R.S.A.*, 77, p. 400, April 1906.
[2] *Proc. Inst. Aut. Eng.*, April 1907.

persists, there is necessarily some loss of heat by radiation to the walls. In order to estimate this loss, I made a series of direct measurements of the actual proportion of the heat of combustion radiated from various flames, luminous and non-luminous, some of which were quoted by Hopkinson in his paper. I found that the heat radiated from an ordinary non-luminous Bunsen flame might amount to 15 per cent. or 20 per cent., but that it depended on the duration of the incandescence and was much smaller, corresponding with a reduction in the size of the flame, in explosive mixtures. It is not possible to estimate separately the exact amount of this loss in the cylinder of a gas-engine, but I think it belongs chiefly to losses of the type A, being proportional to the wall surface exposed, and practically independent of the time, since the duration of the flame is short in the most efficient mixtures. It is probable, however, that part of the radiation loss taking place during the propagation of the flame and throughout its mass is proportional to the volume and not to the surface, in which case it would be represented by a constant term in the expression for the loss of thermal efficiency.'

The only account which I have been able to find of previous systematic experiments on the proportion of the heat of combustion radiated from a flame is in a thesis for doctorate by Robert (the son of Hermann) von Helmholtz. For the majority of non-luminous hydrocarbon flames mixed with air R. Helmholtz finds approximately the same result, namely 5 per cent. of the heat of combustion radiated. According to my experiments this low value is to be explained by the fact that he employed in these measurements small flames, 6 mm. diameter by 60 mm. high, which were probably burning at a comparatively low temperature, and which do, as a matter of fact, give a percentage of this order. In one case he finds 8·7 per cent. of the heat of combustion radiated by a flame 11·8 mm. diameter.

In my own experiments the heat radiated from flames of various sizes, and burning under different conditions, was measured, in calories per square cm. per minute, at a measured distance, by means of an Angström pyrheliometer in a special mounting. The constant of the pyrheliometer, which had shown signs of change, was checked by means of a radio-calorimeter and also by an absolute measuring bolometer. An ordinary wet-meter was employed for measuring the gas supply to the flames, and the same meter was employed in the measurement of the calorific value of the gas with a Boys calorimeter. In some experiments the air supplied to the flame before ignition was measured with the apparatus subsequently employed by Swann[1] in his experiments on the specific heat of air and CO_2. This was useful for estimating the strength of mixture in relation to the appearance of the flame, and for varying the temperature, but could not give quite exact results because the flames were necessarily burning in free air. With the air and gas adjusted as nearly as could be estimated in the proportions required for complete combustion, the proportion of heat radiated varied from 10 to 15 per cent. for burners

[1] *Phil. Trans. A*, 210, p. 208.

from 1 inch to 4 inches diameter. As the air supply was reduced for the same rate of gas consumption, the size of the flame increased and also the heat radiated. A maximum of 15 to 20 per cent. was reached for these burners when a brilliant and well-defined inner cone was formed. If the amount of air supplied was in excess of that required for complete combustion, the radiation fell off considerably in consequence of the reduction in size and fall in temperature of the flame. When the air supply was reduced until the inner cone disappeared, with burners of this type, the flame became unsteady and was reduced in temperature, the radiation falling to about 12 to 16 per cent. With steady luminous flames, of the Argand or bat's-wing type, there was a considerable increase of radiation on excluding air from the flame. With small flames of low temperature the proportion of heat radiated might be as low as 2 or 3 per cent.

These results appeared to indicate that the radiation depended largely on the size of the flame as well as on the temperature, and on the presence of CO or solid C when the air was insufficient for complete combustion. The mixtures employed corresponded fairly with the range available in a petrol motor, but the temperature of the flame in a motor, with ignition at constant volume, would certainly be much higher. A considerable percentage of the loss of thermal efficiency in such cases might evidently be ascribed to radiation. The exact proportion could not be directly estimated, but it occurred to me in preparing this note that the probable effect of radiation on the variation of efficiency with size could be deduced by a more complete study of one particular type of flame, and by measuring the radiation and absorption for different thicknesses. With the assistance of Mr. G. Nelson, I have accordingly repeated and extended some of these observations.

Experiments with a Mêker Burner.

The type of burner selected for these experiments was the Mêker burner, with a nickel grid of 3 cm. diameter, consuming gas at the rate of 0·185 cubic feet a minute. The heat radiated was measured in calories per square cm. per minute by an Angström pyrheliometer at a distance of 52 cm., and the result multiplied by 4522 to deduce the total radiation in calories per minute, assuming the flame to radiate equally in all directions. The lower calorific value of the gas was measured wet under the temperature and pressure of the experiment, and was found to vary from 470 to 500 B.T.U. per cubic foot. With full air-supply, the gas and air being nearly in the proportions required for complete combustion, the burner gives a solid homogeneous conical pointed flame, with no indications of an inner cone. As the air supply is reduced minute cones make their appearance over the grid and finally coalesce into a single steady brilliant inner cone, which increases in size. The percentage of heat radiated rises steadily with increase of size of the flame, from 10·5 with full air-supply to 16 per cent. as a maximum with a large and bright inner cone. Beyond this point the inner cone becomes ill-defined, the flame flickers, and the radiation falls off to 14 per cent., rising again to over 16 as the flame becomes

luminous. These variations are compared in the accompanying table with the approximate composition in volumes of air to one of gas before ignition. The form of the curve depends to some extent on the shape, size, and nature of the flame. It would not be the same for a bat's-wing or Argand flame. The rate of gas consumption was maintained approximately constant, and the size of the flame varied with the strength of mixture.

Total radiation of Mêker burner per cent. of heat of combustion:

Total Radiation per cent.	10·5	12·3	14·0	15·9	14·1	14·6	17
Ratio Air/Gas by vol.	5	4	3	2·5	1·5	1	0

The gas was in all cases completely burnt. The ratio of air to gas before ignition merely describes the nature of the flame. Mixtures in these proportions, if burnt without further addition of air, would not, of course, radiate the same per cent. of heat. With the ratio air to gas$=5$, the duration of the luminous flame was estimated at about a fiftieth of a second.

Intrinsic Radiance of Flame.

The intrinsic radiance of a flame has the same meaning in respect of total energy of radiation that intrinsic brilliance or brightness has in respect of luminosity. It may be measured by the radiation emitted per unit area of surface, but in the case of a flame which is more or less transparent the radiation comes from a finite thickness, and must be measured per unit of solid angle subtended. This measurement may conveniently be effected by means of a total radiation pyrometer of any kind in which an image of the flame is formed on a radiometer or bolometer. A Fery mirror pyrometer was employed for this purpose, the instrument being focussed on the flame at a height of 4 to 5 cm. above the grid, where the flame was steady and sensibly homogeneous.

With this restriction it was found that the intrinsic radiance of the Mêker burner did not vary materially as the air supply was reduced from that necessary for complete combustion, until the inner cone became so large that the flame could no longer be regarded as sensibly homogeneous. This showed that the increase of total radiation simultaneously observed was due chiefly to increase in the size of the flame, and that the increase of thickness of the flame was compensated either by fall in temperature or by increase in absorptive power. The thickness of the flame at the height focussed in the pyrometer varied from 2·8 cm. with full air supply to 3·6 cm. when the inner cone was 3 cm. high and just cleared the area focussed.

In order to determine the manner in which the intrinsic radiance R varied with the thickness x of the flame in the line of sight, and to measure the coefficient of absorption, six precisely similar burners were mounted in a row along the axis of the radiation pyrometer, which was focussed in such a way that the reading was the same for any one of the burners singly or for any combination of the same number of burners at different distances. The pressure of the gas supply was regulated to a constant value, and care was taken to prevent the air in the laboratory from becoming contaminated, which produced a notable

effect on the radiation. Several series of measurements were taken with one to six burners lighted in different orders, for two distinct states of the flame which were easily reproducible, namely (1) with full air-supply and (2) with the inner cones 2·5 cm. high. In the latter case the flames all touched each other, and the layer of flame was 21·6 cm. thick and was sensibly homogeneous.

Summary of Observations.

1. Full Air-Supply, Mean thickness per flame, 2·8 cm.

Number of Flames	1	2	3	4	5	6
Radiation Observed	68	124	171	214	250	282
Radiation Calculated	66	124	173	216	250	282

Formula $R = 473\ (1 - e^{-\cdot 0537x})$

Limit R/x when $x = o$, $= 473 \times 0{\cdot}0537 = 25{\cdot}4$ per cm. thickness x.

Limit of R when $x =$ infinity, $R = 473$.

2. Cones 2·5 cm. high. Mean thickness per flame, 3·6 cm.

Number of Flames	1	2	3	4	5	6
Radiation Observed	72	122	165	197	232	261
Radiation Calculated	66	120	166	201	232	257

Formula $R = 373\ (1 - e^{\cdot 0541x})$.

Limit R/x when $x = o$, $= 373 \times 0{\cdot}0541 = 20{\cdot}2$ per cm. thickness.

Limit of R when $x =$ infinity, $R = 373$.

The observed and calculated values agree as closely as could be expected with the exponential law of absorption, which is fairly appropriate in this case, since the radiation emitted is necessarily of the same quality as that absorbed and the flame is nearly homogeneous. An apparent confirmation of the formula is that the coefficient of absorption is practically the same, namely 0·054 for the two flames. The limit of R/x, when $x=0$, which gives the intrinsic radiance per cm. of flame corrected for absorption, is higher for the case of complete combustion because the temperature of the flame is higher. The limit of radiance for an infinite thickness of flame is higher in the same proportion. The radiation observed for a single flame in case (2) is rather larger than that calculated, because the thickness of a single flame was slightly greater than the mean of several flames in contact. It will be observed that the flame is surprisingly transparent to its own radiation. It is very commonly assumed that, because a flame absorbs precisely those radiations which it emits, and absorbs them in the same proportion as it emits them, the flame would, therefore, be practically opaque to its own radiation, so that the radiation proceeding from the interior of a mass of homogeneous flame might be neglected, and the total radiation assumed proportional to the surface. The above observations show that this is very far from being the case, owing to the relatively wide separation of the radiating and absorbing molecules.

Effect of Temperature and Pressure.

The effect of temperature and pressure on the intrinsic radiance of a flame of this kind can be theoretically predicted with a reasonable degree of probability, but it would be difficult to determine either experimentally. Within moderate limits of pressure, the radiating and absorbing powers of a flame per unit thickness at a given temperature

and composition should both vary directly as the pressure or density. The value of the radiation from a layer of thickness 1 cm. at a pressure of 10 atmos. would be the same as that from a layer of 10 cm. at 1 atmo., assuming that the quality of the radiation or the nature of the combustion were not altered by the pressure. This effect is represented by increasing the absorption coefficient in proportion to the pressure, *leaving the limit for infinite thickness unaltered.*

The effect of temperature is more difficult to estimate because the radiation from a flame is very complicated and there is no means of accurately measuring the temperature. Nernst,[1] from observations by others on the cooling of an explosive gas mixture, maximum pressure about 6 atmos., allowing for convection and conduction, finds the radiation to vary as the fourth power of the temperature. The method is very uncertain, and his conclusion was most severely criticised by Lummer, Bringsheim, and Schaefer, who explained that the radiation was quite different from that of a black body, and that the quality of the radiation was little, if at all, affected by pressure up to 4 atmos.

The principal maxima of emission and absorption in the Bunsen flame spectrum are at 2·8 μ and 4·4 μ. Taking a mean wave-length of 3·5 μ, it is easy to estimate how the intensity should vary with temperature by assuming Planck's equation. The following table gives approximate relative values for comparison with the fourth-power law of the Stefan for the radiation of a black body:—

Absolute Temperature	1000°	1500°	2000°	2500°	3000°
Radiation, Planck	0·016	0·059	0·142	0·233	0·331
„ Stefan	0·009	0·045	0·142	0·347	0·721

The rate of variation, according to Planck's formula for a single wave-length, is much slower than the fourth-power law, and tends in the limit to be directly proportional to the absolute temperature at high temperatures. The actual rate of variation should lie between these limits, but nearer to Planck, *unless carbon begins to separate in rich mixtures at high temperatures.*

Effect of Radiation Loss on the Thermal Efficiency.

Although it is not possible to calculate the absolute magnitude of the radiation-loss in a motor, or to deduce from it the relative loss of thermal efficiency, it is not difficult to see in what manner this loss should vary with flame temperature and with linear dimensions of the cylinder. We may assume for this purpose that the cylinder at the moment of maximum pressure is filled with practically homogeneous flame and that the walls are practically non-reflecting. For similar motors under similar conditions the heat-loss per explosion will vary as the product RS of the intrinsic radiance R and the surface S. The percentage heat-loss should vary as RS/V, where V is the volume of the cylinder. This will vary as R/D, where D is the diameter, for similar motors. Assuming a pressure of 20 atmos. in a cylinder of

[1] *Proc. Inst. Aut. Eng.*, 1909, pp. 457–468.

2 inches or 5 cm. diameter, the equivalent thickness of flame at 1 atmo. is 100 cm., and the intrinsic radiance for a flame of this thickness has already reached within less than half per cent. of its limit for an infinite thickness. The percentage loss due to radiation per stroke will, therefore, vary inversely as the diameter in similar motors, since R will be practically independent of the dimensions in all cases which occur in practice. Since the rate of loss due to radiation diminishes very rapidly with the time, the effect of variation in speed on the radiation loss may be appropriately represented by a factor of the type $(A+B/n)$, where n is the speed in revolutions per minute, as suggested in my paper already quoted at the beginning of the note. From the rapidity of the radiation-loss during ignition it is clear that the A term will be of considerable importance and will affect the comparison of similar motors of different sizes when running at the same piston-speed (n inversely as D) in the manner explained in my paper. I was convinced on general principles that this would turn out to be the case, but without actually measuring the absorption coefficient it was not possible to assert definitely that R would be practically independent of the dimensions.

The variation of the coefficients A and B with flame temperature will be proportional to R, and will be of the nature already indicated. This is corroborated by my analysis of Dr. Watson's observations in a contribution to the discussion on his paper.[1]

Absolute Value of Intrinsic Radiance.

The absolute value of the intrinsic radiance of these flames was determined by comparison with the radiation of a black body with the same pyrometer. The black body temperature for six flames with full air-supply, giving a deflection of 282 scale divisions with the galvanometer, was 679° C. or 952° absolute, for a thickness of 16·8 cm. This means that the intrinsic radiance of such a layer of flame is the same as that of a black body at 679° C.

Assuming the radiation from a black body at a temperature θ Abs. to vary as $E\,\theta^4$ where E is the radiation constant, and has the value $5{\cdot}32 \times 10^{-5}$ ergs per sq. cm. per sec., or $1{\cdot}273 \times 10^{-12}$ gm. cals. per sq. cm. per sec., the radiation from a black body at 952° Abs. or 679° C. would be 63 cals. per sq. cm. per min.

The limiting value of the intrinsic radiance for infinite thickness would be 105 cals. per sq. cm. per min. in case No. (1) with full air-supply, and 83 cals. per sq. cm. in case No. (2) cones 2·5 cm. high. These values would correspond approximately with the initial rates of loss of heat by radiation per sq. cm. of surface in a gas-engine cylinder filled with similar flames at corresponding temperatures. The higher value gives a loss of 175 cal. per sq. cm. in the first tenth of a second. Professor Hopkinson's experiments with a bolometer placed outside an explosion vessel, in which the flame temperature was certainly a good deal higher, give 0·315 cal. per sq. cm. lost in the first tenth

[1] *Phys. Zeit.*, **5**, 1904, pp. 777–780.

of a second after ignition commences?5 cal. in the first tenth after maximum pressure. These are tʕ of the same order of magnitude, and differ in the right directn the value deduced above. They may be regarded as confirmı validity of both methods of estimating the absolute value of the ı loss.

In applying these results to an internal-combugine, it must be remembered that the radiation is not in fact strhogeneous. There are considerable variations of temperature, ffect the quality of the radiation. It appears probable that lumrbon, giving a continuous spectrum, may separate in rich mixturesly if not perfectly uniform. These variations would tend to inc effective transparency of the flame, and the increase of radiati with dimensions. Further investigation will, doubtless, elucidate t points. But, in so far as the flame tends to absorb its own radiati selectively, the theory above sketched may serve a useful purpose as a first approximation.

APPENDIX B.

On Radiation in a Gaseous Explosion. By B. HOPKINSON.

In the First Report of the British Association Committee on Gaseous Explosions attention was drawn to the probable importance of radiation in determining the rate of cooling of the mass of hot gas produced by igniting an inflammable mixture in a closed vessel. In the Second Report reference was made to some experiments which I had made on the effect of coating the walls of the explosion vessel with bright tin-foil. It was found that if a mixture of coal-gas and air of given composition were exploded in a vessel thus lined the maximum pressure reached was the same within one per cent. as that given by an identical mixture when the tin-foil lining was blackened, but the rate of cooling was decidedly less. An experiment was also described in which an attempt was made to measure the actual heat absorption of the walls and the radiation by means of a bolometer of copper strip, whose temperature was recorded photographically during the progress of the explosion and of cooling, the strip being in different experiments blackened, polished, and placed behind a gas-tight screen of rock salt. A considerable difference was found between the blackened and polished surfaces in respect of heat absorption, and this difference was of the same order as the heat absorbed by the bolometer behind the rock-salt screen. The results were strong evidence that the effect of the tin-foil lining on the rate of cooling was due to radiation, and gave an indication of its order of magnitude; but, as tin-foil is not a very good reflector, and as the rock-salt plate was destroyed by the explosion so that only a single experiment with it was possible, I have thought it desirable to do some further work in the same direction.

I have accordingly had prepared a cylindrical cast-iron explosion vessel 30 cm. long by 30 cm. diameter, the whole of the interior surface of which is plated with silver, and I have compared the

...ontaining 15 per cent. of Cambridge results of exploding a polished as highly as possible, and second coal-gas—first with thr over. Precautions were taken to ensure with the surface b omparison experiments should be of identical that the mixture ssures were recorded in the usual way—some- composition. ndicator, and sometimes with an optical indicator— times with ent being used, however, in each set of comparison the same ig. 4 shows superposed the pressure records obtained experi indicator in one such comparison. As in the case of the by t g there is a difference in the rate of cooling, but the difference ti ery much greater—more than twice as great. Further, there oubtedly a difference in maximum pressure amounting to between and three pounds per square inch, which is equivalent to about ° C. in temperature; or, having regard to the higher volumetric heat in the neighbourhood of 2000° C., to perhaps 5 per cent. in thermal energy.

Comparing the two records it will be seen that when the walls are reflecting the gas takes about 1½ times as long to reach a temperature of

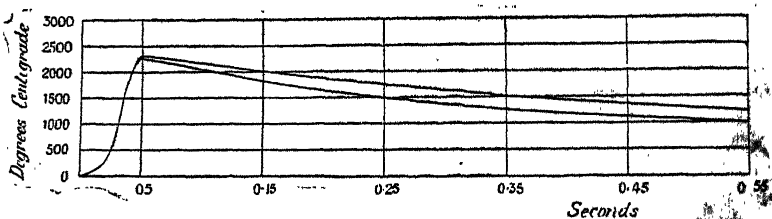


Fig. 4.

1500° C. as it does when the walls are blackened. The actual heat given to the walls in the two cases must be the same, so that the mean rate of cooling during this period in the one case is about 1½ times as great as it is in the other. This proportion remains fairly constant until the temperature has fallen to about 1000° C., when it shows some tendency to diminish. It was found that the precise state of polish of the silver had a great effect on this result—differences in polish hardly appreciable to the eye causing a substantial change in the rate of cooling. In the diagram shown the surface was polished by means of a motor-driven buffing wheel with rouge, and washed with methylated spirit, and then again polished with a leather.

A number of experiments have also been made with a recording bolometer of silver strip, which was sometimes polished and sometimes blackened. Simultaneous records were taken of the gas-pressure and of the temperature of the bolometer. Two such records in which the pressure curves are identical are shown superposed in fig. 5. The bolometer was mounted on a linoleum backing, and there is considerable loss of heat to this backing, which makes the estimate of the absolute

amount of heat absorbed rather uncertain. Since, however, the curves of temperature-rise in the two cases (blackened and polished) are very nearly similar, differing only as regards temperature scale, the proportion of heat lost will be the same in the two cases, and the ratio of heat absorption by the blackened and polished surfaces will be nearly equal to the ratio of the temperatures. The ratio of the temperatures shown in fig. 5 is 0·75 at the end of 0·25 secs. from ignition, which agrees as well as might be expected with the ratio of the rates of cooling deduced from the pressure records with blackened and reflecting walls, having regard to the great effect of small differences in polish upon the rate of cooling. The ratio of the bolometer temperatures increases a little as the gas temperature falls, which again agrees with the gradual approximation as regards rate of cooling disclosed by the pressure records.

Some estimate of the heat lost to the backing can be made as follows: If the temperature of the surface of a solid be caused to vary in a given manner, then the quantity of heat which has passed into it

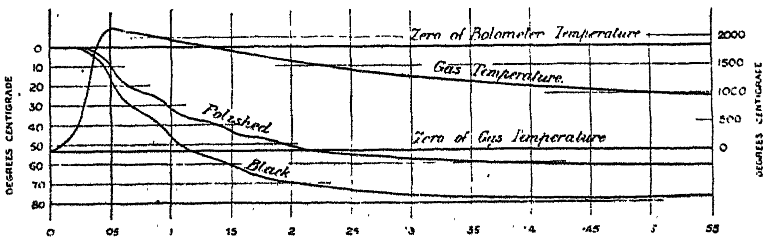


FIG. 5.

at any time can be calculated by means of the Fourier analysis, provided that the product of the thermal conductivity k and the thermal capacity c of the solid is known, being for a given temperature variation proportional to the square root of this product. In the present case the solid is the linoleum backing, and the surface temperature is that of the silver in contact with it, and is given by the bolometer record. The total heat absorbed by the bolometer per square centimetre at any instant can therefore be estimated from the bolometer record, subject only to a knowledge of $\sqrt{k c}$ which occurs as a multiplier, and thence, assuming that the average heat loss over the whole surface is the same as that absorbed by the bolometer, the whole heat given by the gas can be calculated. This heat loss can be obtained also from the pressure record by deducting from the whole heat of combustion the quantity of heat remaining in the gas, whose energy at a temperature of, say, 1000° C. may be considered as known sufficiently nearly for this purpose. The value of the factor $\sqrt{k c}$ is then chosen as to make the heat obtained from the bolometer equal to that deduced from the pressure record. Table I., page 224, showing the absolute heat losses has been obtained in this way.

TABLE I.

Time	Temperatures °C.			Heat in Silver Cals. per sq. cm.		Proportion lost to Backing		Total Absorption		Difference between blackened and polished
	Gas	Silver								
		B.	P.	B.	P.	B.	P.	B.	P.	
0·05	2150	15·9	12·0	0·188	0·142	0·30	0·30	0·245	0·185	0·06
0·10	1940	45·8	31·9	0·530	0·376	0·50	0·50	0·795	0·565	0·23
0·15	1750	61·0	44·1	0·720	0·520	0·70	0·69	1·22	0·88	0·34
0·20	1590	70·0	51·7	0·826	0·610	0·90	0·88	1·57	1·15	0·42
0·30	1350	76·8	59·0	0·906	0·696	1·22	1·18	2·01	1·52	0·49
0·50	1030	78·7	62·5	0·929	0·757	1·70	1·63	2·51	1·94	0·57

The difference between the loss to the polished and blackened surfaces represents the greater part of the radiation from the gas. There is reason to suppose, however, that it does not represent the whole, because it is

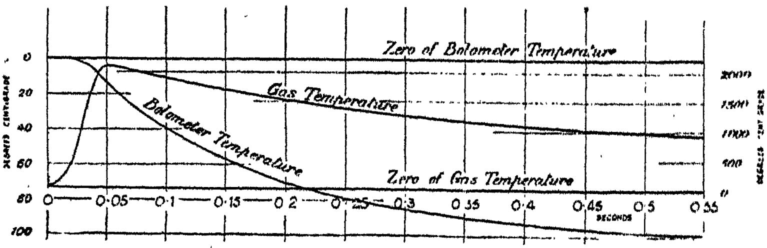


FIG. 6.

probable that at an early stage in the cooling with the polished walls the bright surface of the silver is dimmed by a deposit of moisture.[1]

Finally, a series of records have been taken with a bolometer placed outside the explosion vessel altogether, but exposed to the radiation of the flame through a window of fluorite (fig. 7). This bolometer was of platinum blackened with lamp-black, and the records were taken in exactly the same way as in the other cases. A facsimile of one such record is given in fig. 6, and the Table II. shows the amounts of heat absorbed by this bolometer at different times.

TABLE II.

Time from Ignition	Temperature °C.		Heat in Platinum Cals. per sq. cm.	Loss by Radiation, &c.	Total Absorbed, Cals. sq. cm.	Heat absorbed as percentage of heat of combustion
	Gas	Platinum				
0·05	2090	13·6	0·11		0·11	3
0·1	1870	39·6	0·315		0·315	8·5
0·15	1690	57·4	0·46		0·46	12·5
0·20	1510	70·3	0·57		0·57	15·5
0·3	1290	84·2	0·675	0·025	0·70	19
0·4	1110	91·7	0·735	0·035	0·77	21
0·5	980	96·4	0·770	0·05	0·82	22

[1] The possible importance of such a deposit was suggested to me by Mr. W. T. David, who carried out all the experiments described in this note.

There cannot be any question that the whole of the heat recorded by this platinum bolometer is radiated heat, and I do not think that there is much doubt that, subject to any reflection from the surface of the platinum (which has not been allowed for), the above figures represent the amount of radiation coming through the fluorite window. Fluorite is said to absorb about 5 per cent. of the radiation falling upon it, but no allowance has been made for this. It will be seen that the radiation

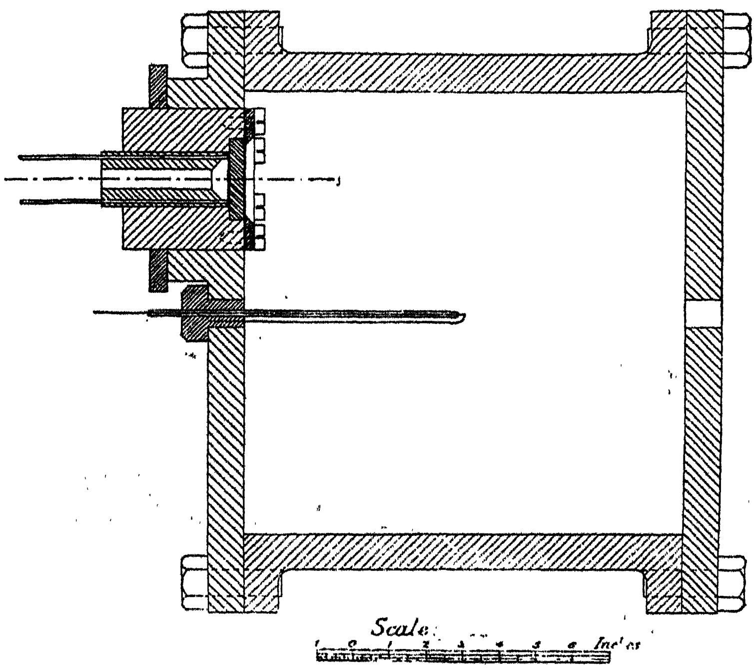


FIG. 7.

here recorded exceeds by about 50 per cent. the difference between the heat absorption with the blackened and polished surfaces. When a plate of glass is substituted for the fluorite plate the heat absorbed by the bolometer is reduced to about one-third of the above amounts, and if the platinum surface is polished instead of blackened, the heat recorded is only 20 per cent. The latter figure agrees fairly well with the result given by Hagen and Rubens for the reflecting power of polished platinum.[1]

APPENDIX C.

Abstracts from various Papers relating to the Application of Heat Radiation from Luminous Flames to Siemens' Regenerating Furnaces.

In September 1884 Mr. Fr. Siemens read a paper before the Iron and Steel Institute in which he described the application of radiant

[1] *Z. für Instr. Kunde*, 22, p. 52 (1902).

heat derived from luminous flames to such purposes as glass ovens and steel furnaces. The greater part of the paper was devoted to practical considerations, but in the discussion which followed he expressed his views as to the theory of the action, and stated that, in order to obtain the best results, from the heat efficiency point of view, the operation should be divided into two parts. In the first part chemical combination took place, the flame was luminous, and the heat should be abstracted by radiation only. In order that the radiant heat might be a maximum, there should be a larger space so that perfect combustion could take place without the gases coming into contact with any solid substance; this space was the furnace proper. In the second part there was no combustion, the flame was non-luminous, and the heat should be abstracted from it by contact, as was done in the regenerative part of the furnace.

Siemens ascribed the radiant heat of the luminous flame to the incandescent particles of carbon, and said that, since flame *is* transparent to its own radiation, not only *does* the surface of the flame radiate, but also its interior; hence a flame radiates far better than a solid substance. 'A solid surface radiates only from its outer surface, and from that surface only towards one [1] direction, while a flame radiated from every point within it, and on its surface in every direction, or from every point of its entire volume towards every direction.' If the area of a solid substance were doubled it would only radiate twice as much, but if the surface of a (geometrically smaller) flame be doubled the radiation would be four times as much.

He specially called attention to the advantage of this method of heating by referring to the experience obtained with glass pot furnaces in Dresden and in Bohemia to which the new method of heating had been applied. There were great gains in every direction: 50 per cent. more glass for the same expenditure of heat, less breakage of pots, the furnace lasted six times longer, and higher temperatures were obtained, so that open pots could be used instead of closed ones. The glass was produced from cheaper materials and was of superior quality.

The statements made in the above paper were severely criticised by German engineers, and therefore on October 26, 1884, Mr. Fr. Siemens read a paper at a meeting of the 'Sachsischen Ingenieur und Architekten Verein' entitled, 'Gasflammofen mit freier Flammen-Entfaltung,' which was published in the 'Civilingenieur,' 1884, and was practically a repetition of his previous paper.

In October 1886 Mr. Fr. Siemens read another paper before the Iron and Steel Institute, entitled 'Combustion with Special Reference to Practical Requirements.' He confirmed what he had previously stated, and added some remarks on dissociation, pointing out that if flame came into contact with heated surfaces there was a tendency to condense 'one or other of the constituents,' and that, therefore, dissociation could take place at comparatively low temperatures; hence dissociation experiments should be carried out in large open spaces. He also remarked that the Bunsen flame, being non-luminous, had but little radiating power.

[1] This is not true unless possibly when the surface is perfectly polished.

In 1886 Fr. Siemens read a paper—published in the 'Zeitschrift des Oesterreichischen Ingenieur und Architekten Vereins,' 1886—entitled 'Die Entwickelung der Regenerativ-Oefen,' in which he further confirmed his previous statements. In this communication he stated that the radiating effect of luminous flames had been originally put into operation at his Dresden glass works in 1877 and in his Bohemian glass works in 1878, but the results were not published for commercial reasons.

Mr. Jeremiah Head read a paper on the Siemens' glass ovens before the British Association (Section G) at the Birmingham meeting in 1886. He pointed out that with direct heating the furnace must be small, whereas with radiant heating the furnace can, and must be, large. He stated that in these large spaces dissociation did not take place, although the temperatures were very high.

Mr. Fr. Siemens published another paper in the 'Civilingenieur' in 1886, entitled 'Die Verhütung des Schornsteinrauches,' in which he stated that the highest temperatures were observed where the flame did not come into contact with the furnace walls. Hence the highest temperature must be due to radiant heat. He again remarked that the surfaces in contact with flame not only hindered combustion, but promoted dissociation.

Gustav Westmann published a scientific inquiry into the 'Siemens' method of glass heating in a paper, entitled 'Siemens' Freier Flammenentfaltung,' read before the 'Verhandlungen des Vereins zur Beforderung des Gewerbfleisses,' 1886. An experiment on a large scale, lasting 24 hours, was made with a glass furnace, in which 25 tons of glass were melted by the gasification of five tons of coal and five tons of lignite. Full particulars of all the measurements are given, and it is shown that the thermal efficiency was 41·9 per cent. and the temperature 1200° C.

Excavations on Roman Sites in Britain.—Report of the Committee, consisting of Professor J. L. Myres (*Chairman*), Professor R. C. Bosanquet (*Secretary*), Dr. T. Ashby, *and* Professor W. Ridgeway, *appointed to co-operate with Local Committees in Excavations on Roman Sites in Britain.*

The Committee have placed the grant of 5*l.*, made at Winnipeg in 1909, at the disposal of the Liverpool Committee for Excavation and Research in Wales and the Marches, for the study of the remains of animals and plants found in the recent excavations on Roman sites at Caersws in Montgomeryshire, and at Carnarvon. The investigation is not yet completed, and the report of its results must be held over until 1911.

The Committee ask to be reappointed, with a further grant.

Archæological and Ethnological Researches in Crete.—Interim Report of the Committee, consisting of Mr. D. G. HOGARTH (*Chairman*), Professor J. L. MYRES (*Secretary*), Professor R. C. BOSANQUET, Dr. W. L. H. DUCKWORTH, Dr. A. J. EVANS, Professor A. MACALISTER, Professor W. RIDGEWAY, *and* Dr. F. C. SHRUBSALL.

APPENDIX.

THE Committee have to express their regret that Mr. C. H. Hawes has been prevented by other engagements from carrying out the further programme of work which was foreshadowed in the Committee's report last year. He has, however, made some progress in analysing the observations which he made during his visit to Crete in 1909 (Appendix I.), and hopes to be able to submit the remainder of his conclusions to the Committee without much further delay. The Committee, therefore, ask to be reappointed with a further grant.

The Committee have received this year a further report from Dr. W. L. H. Duckworth on some of the observations made by him during his journeys in Crete in the year 1903, with comparisons suggested by subsequent journeys in the south of Aragon in Spain. This Report, which forms Appendix II., is an expansion of Section (ii.) of his Special Report (b) presented to the Cretan Committee of the British Association in 1903 and published in 'Brit. Assoc. Report,' 1903 (Southport), p. 409.

APPENDIX I.

A Report on Cretan Anthropometry. By CHARLES H. HAWES.

Since the completion of my last year's expedition to Crete the tabulation and collation of the statistics gathered in 1905 and 1909 have made considerable progress, though not yet complete. Here I deal with the chief measurements only, and those the usual ones, leaving aside for later report the results of a study of the 1,700 sagittal contours of living subjects.

The total number of living persons measured in the two campaigns of 1905 and 1909, together with 199 measured by Dr. Duckworth in 1903, amounts to 3,183. From these must be deducted foreigners, Russians, French, Italians, Armenians, Greeks, Epirots, Albanians, Ægean and Ionian Islanders, and Cretan women and children. A further expurgation has been made in order to simplify, even in the slightest degree, a complex problem. The further omissions comprise

Cretan Mussulmans (who, it is true, possess but little Turkish blood) and orthodox Cretans either of whose parents or grandparents hail from outside the island, however near.

This reduces our total figure, which is the basis of the comparisons made in this paper, to 2,290.

The interest in Cretan ethnology lies not only in the present distribution of types and their external connections, but in their contrast with the prehistoric inhabitants, the builders and artificers of Knossos, Phaestos, Gourniá, Palaíkastro, &c.

Skull Measurements.

It will be remembered that Dr. Duckworth's examination in 1903 of skulls from Palaíkastro (Eastern Crete) showed that the men of ancient Crete of the so-called Middle Minoan Period were dolichocephals, with a small minority of brachycephals. The women were even more dolichocephalic, and the long heads among them in greater proportion than among the men; but, as I shall confine myself to male adults in this paper, I use Dr. Duckworth's figures for men only.

Sixty-four Cretan Males.

Cranial index (average)		73·4
,, (distribution)	dolichocephalic	65·3 per cent.
,,	brachycephalic	8·55 ,,
,,	mesaticephalic	26·15 ,,
Stature (estimated)		1,625 mm.

Since 1903 further ancient Cretan cranial and skeletal remains have passed through my hands, including twenty skulls. By the kindness of Miss Edith Hall the lengths and breadths of five more crania, found this year by Mr. Seager, have recently been communicated to me. These twenty-five skulls, although limited in provenance to the eastern half of Crete, hail from a wider area than the previous sixty-four, namely, from Knossos, Meskiniá, Koumása, Gourniá, as well as Palaíkastro. Thirteen of them belong to an equally early period, but yield a rather higher average cranial index—75·5 as compared with 73·4—and include among them two brachycephals. The remaining twelve show an increasing breadth, agreeing with the archæological evidence for the inroad of invaders. Five skulls from Gourniá, belonging to the beginning of the Late Minoan Period, have a mean cranial index of 76·5, and seven from various sites, belonging to the *end* of this period (L.M. III. after the fall of Knossos), average 79·1, and include no dolichocephals, but three mesocephals and four brachycephals.

It would be more satisfactory to have had a broader foundation, both geographical and numerical, on which to base our knowledge of the physical type of the Minoans; but the evidence of 100 crania (64 male + 13 male + 23 female) from the eastern half of the island, dating back to the beginning of the second millennium B.C., is not to be despised. These are the grounds for assuming the Minoans to have

been dolichocephalic, with a mean cranial index of about 74·0. Alongside of a majority of 60 per cent. long-heads dwelt a minority of about 10 per cent. broad-heads. In stature they were short, scarcely 5 feet 4 inches. This estimate of Dr. Duckworth was confirmed by further measurements made by me last year. This, it is to be remembered, was the condition of things before the prehistoric invasions associated with the names of the 'Achæans' and 'Dorians.'

How do the ancient compare with the modern inhabitants of Crete? Have they changed physically, and how are we to account for the change? Before contrasting the above data with the measurements of 2,290 living male Cretans a word of warning is necessary. We are comparing the *cephalic* index of the living with the *cranial* index of the dead. Assuming a difference of two integers, we shall credit the Minoans with a cephalic index of 76 in place of the cranial index of 74. The modern Cretan has an average cephalic index of 79·0. He is mesaticephalic rather than dolichocephalic, though by no means so broad-headed as the Greek of the mainland, whose mean is about 82·0. The distribution to-day is as follows:—

Dolichocephals (76·9 and below)	29·6 per cent.
Brachycephals (82·1 and above)	24·0 ,,
Mesaticephals (77·0–82·0 inclusive)	46·4 ,,

The increase of the brachycephals and the mesaticephals at the expense of the dolichocephals since the beginning of the Late Minoan Period is here evident.

While the statistical work is as yet under way it is too early to offer a solution of this complex problem, the cause of the physical change in the Cretan people during the last 4,000 years. When we remember that the island has been subject to several invasions, from prehistoric times down to the seventeenth century, the question is certainly an involved one. I will say here that, in order to do away as much as possible with the effects of the last invasion, that of the Turks, I have excluded all Mussulmans from my figures, although there seems not to be much trace of Turkish blood in the majority of the Cretans who profess Islam. Here and there I believe I have traced an individual of Venetian descent; but, having sought Venetians eagerly wherever name or legend suggested, with but little success, and having regard to the wholesale eviction of them at the end of the sieges, I think that they are a negligible quantity in a general survey like the present. If this is true of the Turkish and Venetian invasions, it is much more true of the Saracenic influence, which was spasmodic and ephemeral. In fact, unless we are to call in other causes than the mixture of races for the broadening of the head, the prevalence of the brachycephals and great mixture of the brachycephalic and the dolichocephalic elements to-day seem to me to call for a considerable *prehistoric* invasion of broad-heads.

The distribution of types may help us to some clear conception and to understand some suggestions which I put forward with some diffidence at this early hour.

It will be necessary to bear in mind the geographical outline of the island. About 160 miles long (due E. and W.), it varies from 35 to 8 miles wide (N. and S.). A chain or backbone of mountains runs throughout its length, broken into three chief *massifs*—the White Mountains (8,000 feet) in the west, Mount Ida (8,000 feet) in the centre, and Mount Dicte (6,000 feet) in the east. In the extreme east, beyond the Isthmus of Hierápetra, lies the upland plain of Sitía, c. 2,000 feet in height. At the widest part of the island, to the south, is the largest plain of Crete, the Messará, which, running westward to the 'gateway' of Phaestos, is shut off from the Libyan Sea by a wall of mountains ranging from 2,500 to 4,000 feet high (Mount Kophínas).

Administratively the island is divided into twenty 'eparchies,' and for many reasons this division has proved the most convenient for a starting-point in anthropometric work. The central eparchies have average cephalic indices of 78 and 79; one only, Lasíthi, has a dolichocephalic average of 76·5. Both eastern and western eparchies show an increased breadth—Sélino 80·9 and Sphákia 80·4 in the south-west corner, and Sitía 80·9 in the extreme east.

The percentages of dolichocephalic and brachycephalic individuals are in accord with these differences in averages:—

Central . .	36·0	per cent. dolichocephals,	17·5	per cent. brachycephals
Lasíthi . .	54·5	„ „	6·1	„ „
Sélino . .	13·3	„ „	39·7	„ „
Sitía . .	16·4	„ „	38·1	„ „

The mesaticephals account for the rest. Although we have an identical mean cephalic index of 80·9 in the extreme west and east, these peoples differ not only in stature but in actual head-form, for the Sitíans have *short* heads and the Sélinots *broad* heads. In fact, the latter are the broadest-headed on the island, and the Sitíans barely escape being the narrowest-headed, although their heads are the shortest. It is possible that we have to deal with an invasion of Northern brachycephals (ultimately of the tall Illyric stock) into the west, and another in the east of Asiatic brachycephals from the uplands of Asia Minor.

If the dolichocephal once possessed the land, and the brachycephal was, in the main, an invader, we might expect to find the original inhabitants driven up into the mountains; and this is the case. But this general statement requires some modification. It would be nearer the truth to say that the dolichocephal is not absent from the plains but predominates in the mountains. The homes of the long-heads are on the slopes of the mountain *massifs*—the White Mountains, Mount Ida, and Mount Dicte—as also in the range which shuts off the rich Messará Plain from the Libyan Sea. Of these, the best example is Mount Dicte, the 'birthplace of Zeus,' where, before the Northern god came to the island with his broad-headed contingent, the Cretan Rhea was worshipped. Here in the mountain-plain of Lasíthi, 2,700 feet above the sea, shut in on all sides by towering summits, and only to be reached by toilsome tracks from the plains below, is a true dolichocephalic centre with a cephalic mean of 76·5. The long-heads outnumber the

broad-heads by nine to one, more than even among the 64 ancient skulls examined by Dr. Duckworth. This is a *true centre*, for we find this dolichocephalic element radiating in all directions into the neighbouring eparchies of Pedhiádha, Mirabéllo, Hierápetra, and Viánnos.

The other mountain *massifs* are not true centres; for, although the dolichocephals are most numerous, the mountains, towering up 8,000 feet, form a barrier to the south, and the long-heads cluster on the northern slopes only. This is true of the White Mountains, where in one village alone of Upper Kydhonía, Lakkoús, the home of the late Dr. Jannáris, the 65 men I measured averaged 76·9, against 79·9 in the plains of the same eparchy. The other mountain *massif*, Mount Ida, plays a similar part, and on the northern side, in the upper portion of Mylopótamo, my records show 83 subjects averaging 76·5. The mountains to the south of the Messará Plain, though not so lofty, slope steeply to the sea, and being shut off from the main centres, offer a most undesirable region for any invader to occupy in a hostile country. The region is sparsely populated, and the 28 subjects measured in that part which falls within the eparchy of Monophátsion average 76·9, compared with 80·9 in the Messará Plain immediately below.

These four mountainous regions appear to be the strongholds to which the earlier inhabitants have been driven by successive invaders, and strong confirmation of this hypothesis comes from the method by which I arrived at it. A map of the cephalic index eparchy by eparchy offered no clue. A suspicion of differences between mountain and plain suggested the cleavage line of 1,000 feet altitude as a criterion of classification, but this failed in some cases, though successful in others. It was arbitrary and did not always serve as a register of accessibility. It then occurred to me that in a land of such marked physiographical features as Crete, Achæans, Dorians, Venetians, all had probably followed much the same routes as the Turks in the seventeenth century. I therefore made a map of the Turkish occupation of the island according to the census of 1881, before the latter-day exodus. This showed that from centres on the north coast of the island—Canea, Rethymo, Candia, and Sitia—the lines of immigration radiated southward, stopping short at the foot of the mountains, with but one exception, to which I shall refer later. This general truth is particularly well illustrated in the many lines of occupation stretching south from Candia, the greatest Turkish centre, which all stop short abruptly at the foot of the Messará Mountains. Three great blank spaces stand out on the map between these lines of immigration—Mount Dicte with the fringes of the neighbouring eparchies, the northern slopes of Mount Ida, and both northern and southern sides of the White Mountains. These blank areas are those which we have already found occupied by the predominant dolichocephal, with one notable exception, the southern slopes of the White Mountains. This region, where the Turks have never yet held sway, this eparchy of *Spahákia*, where the Sphákiots have successfully repulsed Turk and Venetian alike, and, isolated in a sterile, rocky home, proudly claim Dorian descent, is the one outstanding exception to the rule that the mountains are the refuge of the dolichocephals. I believe this

significant exception, when fully understood, will prove extremely instructive in the study of prehistoric migrations.

The Dorian migration into Crete has historical authority, and it is probable enough, apart from the anthopological evidence, that a stream of these people reached this south-western part of the island, since ships driven by a strong wind southward would find it dangerous to land on the northern coast, as archæologists know to their cost. There is no harbour on the south coast to compare with Loutro, the port of Sphákia, where St. Paul's companions advised wintering; it possesses a double harbour and gives shelter not only from the north-west and north-east, but also from the south-west winds. Modern travellers commonly report the absence of ports on the south coast of Crete, unaware that native Spkákiot ships ply to Odessa with their great cheeses, hides, and charcoal, and that Spkákiot vessels were reported in the Black Sea during the Venetian occupation of the island, and at Constanza in 1821. To-day there are more harbour-men employed at Spkákia City and its port, Loutro, than in any other Cretan towns, excepting Canea, Candia, and Rethymo. Immigrants landing at Loutro had no choice but to settle on the southern slopes of the White Mountains, sterile, and therefore sparsely inhabited, where to-day we find a majority of broad-heads.

I referred above to one exception to the rule that Turkish occupation stopped short at the foot of the mountains. This example is found on the southern slopes of Mount Ida. The longest line of communications of the Turkish occupation was the one which, leaving Candia, passed along the eastern slopes of Mount Ida, swung round to the south *viâ* that ancient shrine of the Minoans, *Kamáres*, and, doubling the southern slopes of the mountain, crossed by a rich valley the eparchy of Amárion, and ended in the northern port of Rethymo. The northern slope of Mount Ida is a stronghold of the old race; the southern is not, because it was crossed by a high-road of immigration from one base to another.

In all this I would not be misunderstood. I do not attribute the brachycephalic increase to the Turks, but, taking them as guides, I have attempted to show how similar and earlier lines of settlement and communication, pursued by numerous invaders, all broad-headed, with the exception of the Saracens, would account for the present hedging in of the dolichocephalic element.

Before I pass to comparisons of stature let me add some evidence from modern skulls. In the garden of the famous monastery of Arkádhi, besieged by the Turks in 1866, is a memorial tower, the bottom of which is filled with some hundreds of skulls of fallen heroes of the revolutions of 1821 and 1866. Dropping through the floor into the gruesome depths below, I selected 26 crania, which, on examination, yielded an average cranial index of 74·2. Of these, 54 per cent. were dolichocephalic, and only 12 per cent. brachycephalic. These figures are almost identical with those of the Minoan skulls. Arkádhi is on the north-western slopes of Mount Ida, a few miles from the Mylopótamo border. Although not all the fighters came from the immediate neighbourhood, yet they probably hailed in the main from the mountains.

Stature.

The average stature of Cretans to-day is 1,685 mm. (5 feet 6¼ inches), a considerable increase on the estimated stature of the ancient Cretans, which was 1,625 mm. (5 feet 4 inches). In the west the averages are: For the eparchies of Kydhonía 1,723 mm. (5 feet 7¾ inches) and Sphákia 1,711 mm. (5 feet 7½ inches), diminishing in the east to Mirabéllo, 1,664 mm. (5 feet 5½ inches), and Hierápetra, 1,665 mm. The statistics of stature mapped out by eparchies, or according to cephalic index, or by mountain and plain, present only a seeming confusion, with but one obvious trend, an increase in stature as we journey westward. Yet I think it is possible to distinguish some significant facts amid this apparent confusion.

The first is that the people in the plains are, with some exceptions, shorter than those in the mountains.

The second is that the long-head is taller than the broad-head in 15 out of 20 eparchies, and as the mountain villages yield a majority of dolichocephals—descendants of the original inhabitants of Crete, as I hope to have established—it seems that they have increased in stature at a higher altitude. When we remember that the Minoans were a short people and dwelt chiefly on the coast, this upward trend in stature and habitat seems to have gone on *pari passu*. This fact comes out more clearly when we turn directly to the mountain areas where we have already found the long-heads. In Lasíthi, where the cephalic index and the proportion of long-heads to broad-heads of the Minoans is almost exactly reproduced, the average stature for 99 men is 1,676 mm., an increase of 51 mm., or 2 inches, on the Minoan average. The dolichocephals of Lasíthi have an average of 1,685 mm., compared with 1,646 mm. for the brachycephals. Kydhonía Province, on the northern slopes of the White Mountains, has an average of 1,740 mm. for the dolichocephals and 1,715 mm. for the brachycephals. This increased stature of the moderns also holds in the Messará Mountains and Mylopótamo on the northern side of Mount Ida, although in this last case it is reduced by the inclusion of the poverty-struck villagers of Kameráki, a hamlet unknown to the map, boasting no *kappheneion* (café), not even the pretence of a store, the poorest village that I have come across in my wanderings in Crete. Here the average stature of 10 men was 1,600 mm. (5 feet 3 inches) only. Another example of the effect of poverty on stature is to be found in the island of Gavdos (anc. *Clauda*), where the average of 20 men was 1,634 mm. (5 feet 4¼ inches), compared with their nearest neighbours and kinsmen, the Sphákiots, of whom 284 had an average height of 1,711 mm. (5 feet 7½ inches).

The third fact, already noted, is that the people of the western half of the island are taller than those of the eastern half. Both dolichocephals and brachycephals are tall, over 1,700 mm. (5 feet 7 inches), and the former have a slight advantage. The distribution is here somewhat peculiar. On the northern side of the mountain are tall long-heads; on the southern, tall broad-heads; in a neighbouring eparchy are short broad-heads alongside tall long-heads. The puzzle is to account for the tall long-heads and broad-heads in the west. If there

was a Dorian invasion, it appears to have made its entry on the south coast into Sélino, where the brachycephal outnumbers the dolichocephal by three to one, and into Sprákia, where the ratio is three to two, and 86 out of 284 men are over 1,700 mm. in height. The tall dolichocephal of the west exceeds the long-head of the east in stature by at least 40 mm. A careful comparison of numbers and percentages of both tall and short dolichocephals and tall and short brachycephals throughout the island reveals an abnormal number of tall dolichocephals in Kydhonia and the neighbouring region. In other words, everywhere else the ratio of tall long-heads to short long-heads and of tall broad-heads to short broad-heads is approximately the same; here the tall dolichocephal is to the short dolichocephal as 50 to 1. Is this due to differences of soil, fertility, a better-watered country, or to special social conditions? After careful consideration I do not think so. The suggestion has been made that the great stature of Kentucky men is due to the bone-building qualities of water in a limestone region; but in Crete, speaking generally, it is the east that is a limestone district, while the west is composed of talc-schists.

Nor do I think it necessary to call in an invasion of tall long-heads. May not the Kydhonians, whom Homer (*Od.* xix. 176) mentions as one of the peoples inhabiting Crete, have been taller than the Eteocretans of the eastern half, whose stature we have established as 1,625 mm.? We know that a branch of the Mediterranean race, called by Dr. Deniker the Atlanto-Mediterranean, was of greater stature than the rest. The western end of the island is as yet an archæological blank, well-nigh until classical times. We have no ancient skulls or bones from the west, saving a tiny fragment from a pavilion-shaped tomb belonging to the end of the Minoan era.

The records of stature for Kydhonia are striking. One hundred and sixty-seven men from the whole of the eparchy average 1,723 mm. (5 feet 7¾ inches); 67 dolichocephals average 1,740 mm. (5 feet 8½ inches), of whom 25 exceed 5 feet 9 inches in stature. Out of the 167 persons there is but one short dolichocephal (under 1,650 mm.), and in the neighbouring eparchy of Sélino out of 83 there is not even one. This tall dolichocephal also exists to the number of 39 out of 284 persons measured in Spհákia. It seems much more likely, considering the isolation, pride of endogamy, and bellicose nature of the Sphákiots, that these tall long-heads are the remnants of an earlier race rather than intruders since the Sphakiots themselves.

Turning to Sitía in the extreme east, where a moderate upland presents no sharp contrast of mountain and plain, where the brachycephals outnumber the dolichocephals by nearly five to two—a complete reversal of the time when the Minoan dolichocephals were to the brachycephals as eight to one—the increase in stature of the modern long-head is not great (1,625 to 1,663), and he is exceeded in stature by the intruding Asiatic brachycephal, whose stature is 1,678 mm.

To sum up, among modern Cretans the dolichocephals are generally taller than the brachycephals. The dolichocephals in the mountains are taller than their ancestors, the Minoans, who lived by the sea.

The exceptional tallness in the west of the brachycephals seems to be due to an early inroad from the north; that of the dolichocephals of the west may be due to the greater stature of the ancient Kydhonians as compared with the Eteocretans of the east.

Eye-colour.

There remains a word to say on the colour of eyes. These records are only in course of tabulation; I speak, therefore, from a cursory perusal. Classing blue, grey, and green eyes together as light, in contrast with the hazel, light brown, medium brown, and foncé, I find there is a somewhat surprisingly high percentage of light eyes for the whole of Crete—namely, 29. The percentages vary from 18 in Lasíthi eparchy to 40 in Sitía. The distribution offers no obvious clue. Light eyes are about equally divided between east and west, with the highest and lowest averages in the eastern half. Kydhonía 34 per cent. and Sphákia 32½ per cent. in the west are matched by Pedhiádha 33 per cent. and Hierápetra 34 per cent. in the east. Sélino, next door to Sphákia, has the low average of 26 per cent., and compares with Mylopótamo 25 per cent., which two eparchies form so strong a contrast from the point of view of the proportion of long-heads to broad-heads. Sélino has three brachycephals to every dolichocephal, and Mylopótamo has three dolichocephals to every brachycephal.

Speaking of the island as a whole, the numbers of light eyes are equally divided between the short and the tall, the dolichocephals and the brachycephals, in proportion to the number of individuals, so that apparently it is impossible to distinguish by percentage of light eyes one type from another. However, ethnical differences may lie concealed under diverse combinations in different areas, and further study may reveal them. I fail to trace, what is generally expected, a greater frequency of light eyes in the mountains, but it should be remembered that the predominance of the older brunette race in these areas furnishes a more than counteracting tendency. This is well illustrated in Lasíthi, which has the lowest percentage of light eyes (18), as well as the closest approximation in head measurements to our records for Minoans.

My census of 2,000 school-children taken throughout the island, whether compared *in toto* or by eparchies with adults, shows a surprisingly diminished average, 18 per cent. instead of 29 per cent. This striking difference, obtained from figures carefully gathered and compiled, calls for a radical explanation; but, apart from such, is there here a tendency to reversion to type?

I am only too conscious of the fragmentary condition of this report, of the many characteristics and questions of variation which do not receive mention; but the material is gathered, and in the main tabulated, and it should be only a matter of time before the observations made throw light on questions of migration and descent in the most interesting island of the Mediterranean.

APPENDIX II.

Observations on 104 School-children at Vori and at Palaikastro in Crete. By W. L. H. Duckworth, *M.D., Sc.D.*

Contents.

In the course of a journey in 1903 from Candia to Palaikastro, in Crete, I had the opportunity of measuring and observing a number of school-children (fifty-nine boys and twenty-five girls) at Vori, a small village distant about five miles from the southern coast of the island, near the traditional site of 'Fair-Havens,' and about two miles from the well-known prehistoric site called Phaestus. Later on, in the same year, I supplemented these measurements by the addition of twenty more records for schoolboys of corresponding age at Palaikastro, or, to be more strictly accurate, at Angathi, the neighbouring village, one of the most eastern settlements in Crete. A preliminary report was submitted to the Committee in 1903, and published by the British Association in the Southport volume of its Proceedings. In the present report I have worked out the data more fully than was possible in 1903, and in this instalment I shall deal principally with the data relating to Cretan boys, since they were the more numerous; moreover, comparisons with adult males are more easily made; and, lastly, it is interesting to compare the results with those obtained by me last year in the south of Aragon, in Spain, from one hundred schoolboys of comparable age. For the publication of the records from Spain I am indebted to the Council of the Cambridge Antiquarian Society.

Little need be said about the conditions of life in Crete and the character of the land, for recent writers have dealt sufficiently with these questions. I may, however, state that my impressions lead me to believe that these conditions are not very different in Crete and in Aragon. At the same time I must add that both the Cretan villages visited are within the zone of malaria, that I saw undoubted cases of the sequels of malaria supervening in childhood, and that this liability, which is probably minimal, or absent, in the part of Aragon available for comparison, is important in its relation to, and effects upon, physical development. In this connection special mention is made of the fact that the physique of these Cretan children is frequently, if not universally, poor, and often a boy was found to claim an age in years greater by about 30 per cent. than that which we would have assigned to a British boy of similar stature and physical development. The relative poorness of the food, both in quantity and quality, taken together with their unavoidable exposure to extremes of temperature according to the season (for the winter is often severe in Crete), contributes to a combination of circumstances with which this deficiency in corporeal development can be justly charged.

A.—CRETAN SCHOOLBOYS (ages from 5 to 16 years).

Observations were made under the following heads:—

I. *Colour of the hair.*—Table I. exhibits the results of the investigations carried out:—

TABLE I.—*Number, Hair-colour, Eye-colour, and Age: Mean Age* 9·9 *years.*

Seventy-nine Cretan Schoolboys at Vori and Palaikastro							
Place & No.	Hair-colour	Eye-colour	Age	Place & No.	Hair-colour	Eye-colour	Age
Vori				Vori			
1	Jet black	Dark brown	6	43	Brown	Dark brown	7
2	Fair	Dark brown	8	43a	Brown	Dark brown	7
3	Brown	Dark brown	8	44	Dark brown	v. dk. brown	9
4	Dark	Dark brown	7	45	Dark brown	Hazel	8
5	Fair	Grey	8	46	Black	Jet black	5
7	Dark	Dark	9	47	Fair	Dark brown	7
8	Black	Dark brown	9	48	Dark brown	Dark brown	7
9	Black	Dark brown	8	48a	Fair	Dark brown	7
10	Fair	Hazel	8	48b	Very fair	Hazel	8
11	Black	Dark brown	15	49	Fair	Dark brown	9
12	Brown	Hazel	11	50	Fair	Hazel	10
13	Fair	Grey-green	7	51	Fair	Hazel	10
14	Black	Dark brown	8	52	Fair	Blue	6
15	Dark brown	Dark brown	11	53	Fair	Hazel	6
16	Brown	Dark brown	11	54	Brown	Dark brown	5
17	Black	Dark brown	11	55	Dark brown	Dark brown	5
18	Fair	Dark brown	11	56	Fair	Green	6
19	Fair	Dark brown	10				
20	Fair	Grey-green	10	Palaikastro			
21	Fair	Grey	10				
22	Fair	Dark brown	12				
23	Brown	Dark brown	10	1	Dark brown	Dark brown	8
24	Brown	Hazel	16*	2	Jet black	Dark brown	10
25	Fair	Grey	13	3	Light brown	Grey	7
26	Brown	Hazel	13	4	Brown	Light brown	8
27	Dark brown	Green	13	5	Light brown	Hazel	9
28	Brown	Dark brown	10	6	Dark brown	Dark brown	12
28a	Fair	Light brown	12	7	Dark brown	Grey	13
29	Dark brown	Dark brown	12	8	Dark brown	Grey	13
30	Brown	Dark brown	11	9	Dark brown	Dark brown	13
31	Jet black	Medium brown	12	10	Light brown	Grey	11
32	Dark brown	Dark brown	10	11	Dark brown	Dark brown	11
33	Dark brown	Dark brown	15	12	Jet black	Hazel	12
34	Black	Dark brown	12	13	Dark brown	Hazel	13
35	Brown	Dark brown	13	14	Dark brown	Dark brown	13
36	Dark brown	Dark brown	14	15	Dark brown	{ Dark brown	10
37	Fair	Blue	14			{ Grey (1)*	
38	Dark brown	Grey	15	16	Brown	Dark brown	13
39	Brown	Dark brown	6	17	Dark brown	Green	16
40	Dark brown	Dark brown	10	18	Brown	Medium brown	13
41	Fair	Blue	6	19	Brown	Dark brown	10
42	Brown	Dark brown	7	20	Light brown	Hazel	7

* Different colours in the same individual.

The analysis of this table yields the following percentages:—

TABLE II.—*Hair-colour and Age: Percentages.*

Seventy-nine Cretan Schoolboys						
Colour	No.	Per Cent.	Mean Age	Colour	Per Cent.	Mean Age
Very fair .	1	1·26	8 years	Light .	32·80 (adults 3·96)*	8·92 years
Fair . .	21	26·50	9·05 „			
Light brown.	4	5·04	8·5 „	Medium.	22·68 (adults 13·3)	9·9 „
Brown . .	18	22·68	9·9 „			
Dark brown .	22	27·76	11·2 „	Dark .	44·14 (adults 83·1)	10·62 „
Dark . .	2	2·52	8·0 „			
Black . .	7	8·82	9·7 „			
Jet black .	4	5·04	10·0 „			
Total . .	79	99·62	9·9 „			

* From my observations on adult Cretans. In England a similar progressive darkening of the hair is the rule (cf. *British Assoc. Report*, 1883, Table XI., pp. 278, 279).

This statement shows that the darker tints of hair coloration are preponderant; also that the influence of age in this respect is as distinct as in other cases; and the general rule as to the darkening of the hair during the period from childhood to maturity is evidently followed in this instance. For comparison with another instance from Southern Europe I give a similar table for 100 school-children at Alhama de Aragon in Central Spain. It should be noted that this table differs slightly from that published by me in the Proceedings of the Cambridge Antiquarian Society (vol. xiv.). The table there published has been revised, and stands as follows:—

TABLE III.—*Hair-colour of* 100 *Schoolboys at Alhama de Aragon.*

Colour	Per Cent.	Mean Age	Colour	Per Cent.	Mean Age
Very fair	3	7 years	Light .	25	8·24 years
Fair	6	8·6 „			
Light brown. . .	16	8·31 „	Medium.	32	8·12 „
Medium brown . .	32	8·12 „			
Dark brown . . .	35	8·77 „	Dark .	42	8·83 „
Jet black . . .	7	9·14 „			
Red	1	12·0 „	Red .	1	12·0 „
Total . . .	100	8·5 „	(Red .	1	12) „

In this instance (though the full details are not given) the general significance is the same for Aragon as for Crete. But the depth of pigmentation is usually greater in Crete. Beddoe's 'Index of Nigrescence' is +25 (cf. Table XII.). I have no record of a case of red hair among the Cretan children examined by me, and I recall to mind but a single instance in either adult or immature persons in that island.

With regard to the association of hair-colour and eye-colour I may notice that in general the usual rule applies to Crete, that is to say, fair hair or light-coloured hair may be accompanied by dark eyes (cf. on this point the paper on Aragonese school-children, mentioned above), whereas it is much more unusual for the reverse combination to appear. Here, at Palaikastro, this unusual combination did actually occur twice. The dark-brown hair in these boys was associated with eyes of a grey tint merging into the hazel colour so distinctive of many Cretans.

In the majority of instances the hair is straight or somewhat wavy, but not closely curled.

II. *Colour of the Eyes.*—Turning to the data (provided in Table IV.) for the colour of the eyes, analysis gives the following summary of the records:—

TABLE IV.—*Eye-colour and Age.*

Seventy-nine Cretan Schoolboys						
Colour	No.	Per Cent.	Mean Age	Colour	Per Cent.	Mean Age
Blue	3	3·75	8·66 years	Light	17·5 (Aragon† 13·1) (Adults 21·23)	0·2 years (Aragon† 7·14 years)
Grey	9	11·25	11·10 ,,			
Grey-green	2	2·50	8·50 ,,			
Green	3	3·75	11·66 ,,	Medium	25·0 (Aragon† 46·5) (Adults 65·98)	10·5 years (Aragon† 8·98 years)
Light brown	2	2·50	10·00 ,,			
Hazel	13	16·25	10·07 ,,			
Medium brown	2	2·50	12·50 ,,			
Dark	1	1·25	9·00 ,,	Dark	57·5 (Aragon† 40·4) (Adults 12·98)	9·6 years (Aragon† 8·27 years)
Dark brown	43	53·75	9·90 ,,			
Very dark brown	1	1·25	9·00 ,,			
Jet black	1	1·25	5·00 ,,			
	80*	100·00	9·90 ,,			

* One individual (Pk. 15) having eyes of different colours, is counted twice.
† Comparable data for 100 schoolboys at Alhama de Aragon, Spain.

Upon this table I would comment as follows: First, the gradation in depth of pigmentation does not follow the same sequence in respect of age, as was observed to obtain in the case of the hair. In other words, the eye-colour is seemingly independent of age in years. Again, the Aragonese schoolboys provide exactly the same characteristics as those of Crete in this feature of eye-colour: the percentage figures for both series of children will be found in the table. Lastly, the adult Cretans seem to provide a contradictory result. This paradox may well have a two-fold explanation. For the adults include a large proportion of men from the most eastern province of Crete)Sitia), where I suspect the medium tints preponderate. A second contributory cause may be found in the fact that I was obliged perforce to observe the adults in the open air, often in a strong light. The children were seen in a

[1] In England the eye-colour seems to darken with age to maturity, but not nearly in such marked degree as the colour of the hair (cf. *British Assoc. Report*, 1883, Table XI., pp. 278, 279; also Beddoe, *The Huxley Lecture*, 1905.

schoolroom, where the light was to some extent subdued. I am not aware of this matter having been tested, but on reflection it seems likely that where the pupils of the eye are dilated, then, in the dim light productive of that effect, the narrow iridic zone (which is all that appears) may be judged to be of darker tint than when the reverse conditions obtain. At the time I did not think of this as a possibly disturbing factor, but, in any case, the bulk of the schoolboys (those at Vori) were first examined, the men coming in only at a later date.

Reference should be made to the tabulations (in Tables XI. and XII.) of the association of hair-colour and eye-colour, and also of the indices based upon these data.

III. *Head-length.*—The mean value of this dimension in seventy-nine boys (of an average age of 9·9 years) is 173·2 mm. This is the greatest length measurable from the glabella. But, as in the Aragonese and in other school-children, the maximum head-length will be found between a supra-glabellar (*i.e.*, ophryonic) point and an occipital point. The gradual increase in this dimension may be illustrated as follows:—

Mean value (in mm.) of the maximum glabello-occipital length of Cretans (males only):—

(*a*)	Boys of the average age of 6 years	(9 examples)	171·0 mm.
(*b*)	„ „ „ „ 9·9 „	(79 „)	173·2 „
(*c*)	„ „ „ „ 15 „	(7 „)	179·4 „
(*d*)	Adults from all parts of Crete	(200 „)	186·3 „
(*a*′)	Boys of the average age of 11·1 years from Sitia province	(20 „)	171·2 „
(*b*′)	Adult Cretans of Sitia province	(131 „)	176·3 „

This table shows that the increase in head-length continues after puberty. The amount of this later increase is not nearly so great as in a distinctly dolichocephalic type, such as the native Aragonese. Comparison of the figures with those provided by Aragonese school-boys (and recorded by me in the 'Proc. Cambr. Antiq. Soc.', vol. xiv.) will show the correctness of this conclusion. It should be noted, lastly, that the inhabitants of Sitia province show a smaller relative increase (cf. sections (*a*′) and (*b*′) of the table) than Cretans in general.

IV. *Head-breadth.*—The mean value of the head-breadth is 140·2 (79 examples): its mean value at different ages is shown in the table following:—

Mean value (in mm.) of the maximum cephalic breadth (of Cretans):

(*a*)	Boys of an average age of 6 years	(9 examples)	135·4 mm.
(*b*)	The whole series; mean age 9·9 years	(79 „)	140·2 „
(*c*)	Boys of an average age of 15 years	(7 „)	143·1 „
(*d*)	Adults (males) from all parts of Crete	(200 „)	148·3 „
(*a*′)	Boys (mean age 11·1 years) of Sitia province	(20 „)	143·0 „
(*b*′)	Adult (males) of Sitia province	(131 „)	148·7 „

In this case again the increase is comparatively continuous, and the sudden acceleration after puberty, so marked in the dolichocephalic Aragonese boy, is hardly noticeable in Crete. Moreover, the boys of the Eastern province have heads which are even more precocious in attaining the mean breadth for the age of puberty than those in other

districts. At the same time, the same heads (of youths in Sitia province) have to 'make' a greater amount of growth before this is completed.

V. *Cephalic Index.*—The mean value of this index in 79 boys is 80 9. As in the cases of its contributory factors (head-length and head-breadth), I have prepared a list of data giving the values of this index at different ages:—

Mean value of the cephalic or breadth-index of the head (in Cretans):

(*a*)	Boys of an average age of 6 years	(9 examples)	79·2 mm.
(*b*)	The whole series (mean age 9·9 years)	(79 ,,)	80·9 ,,
(*c*)	Boys of an average age of 15 years	(7 ,,)	79·8 ,,
(*d*)	Adults (males: from all parts)	(200 ,,)	79·6 ,,
(*e*)[1]	Adults (males: from all parts)	(1600 ,,)	79·2 ,,
(*a'*)	Boys (mean age 11·1) of Sitia province	(20 ,,)	83·53 ,,
(*b'*)	Adults (males) of Sitia province	(131 ,,)	84·3 ,,

Having regard to the small number of examples in (*a*) and (*c*), I think the first conclusion must be that, in general, the numerical value of this index is very constant from childhood onwards in Crete. This is not the case in Aragon,[2] where the index changes after puberty to a considerable degree. This difference may very likely be constant for the contrast of dolichocephalic and brachycephalic heads. If we confine our attention to Crete, another important inference may be drawn from the last table. It is this: that the most eastern Cretans are distinguished by a degree of brachycephaly higher than the average for that island. A marked degree of brachycephaly is already present in the young Cretan of Sitia (the Eastern province).

As regards the significance of this difference, I have already suggested[3] that the history of the large number of colonists introduced by the Venetians (during their occupation of Crete) is well worth investigation. The modern peasant of Emilia has a head characterised by brachycephaly in a high degree. But Venetian colonists need not have been, and probably were not, drawn from the immediate surroundings of Venice. When we consider the influence exercised by the Republic over Dalmatia and Illyria before the Venetian expansion commenced on the Italian side of the Adriatic, we may justifiably think of those territories as possible sources whence Crete was re-stocked with inhabitants in the later Middle Ages. In fact, we know that in the year 1471 A.D. the province of Sitia was largely depopulated. This is clearly shown by the Venetian Archives translated by the late Dr. Noiret,[4] and Adrovasti is actually mentioned in a list of the abandoned villages. This depopulation was effected by marauding bands of Turks.

In Dr. Noiret's invaluable translation I find evidence that the interest of the Venetians was almost entirely in their settlers, who seem to have been of Italian origin. In a list of thirty-seven names of such persons (who had got into trouble through raising loans which they

[1] Hawes, *British Assoc. Report*, Dublin, 1908.
[2] Cf. Duckworth, *op. cit.*, p. 44.
[3] Cf. *British Assoc. Report*, 1903.
[4] Cf. *Bibl. des Ec. françaises d'Athènes et de Rome*, fasc. lxi. (1892), pp. 520, 521, Univ. Lib. 535c. 40, 34.

proved unable to repay) I find not one definitely Greek, but the name Sclavo occurs thrice.[1] This was in 1428.

But in 1390 a record [2] throws a little light upon the Venetian method of dealing with the aboriginal Cretans, for on June 28 of that year a reissue is made of an earlier order dating from 1364, whereby prohibition is enacted of settlement, of agricultural labour, and of sowing corn in the plain of Lasithi and on the surrounding heights. The penalties are severe, and evidently the native refugees in the hills were to be given no chance of looting stores or crops.

But direct references to a native population are wonderfully scarce in these Archives.

As regards incoming ethnic elements, there are only three records to notice. These, though vague, are not by any means without interest.

The earliest is in 1414,[3] when Abraynus Anteron, 'the Armenian,' seeks permission to bring from Trebizond 880 'families' to escape from the 'Turks.' He wishes to bring these families to Crete; he is given his choice of Eubœa or Crete: promises are made of good treatment, 'quod loca nostra repleantur gentibus et specialiter personis que (*sic*) querunt vivere pacifice, juste et ex sudore suo.'

Then in 1417 [4] permission is given to the Cretan Government to allow Turkish prisoners to establish themselves and their wives in Crete.

The last record is in 1479,[5] when orders are issued for the protection of forty families, refugees from the island of St. Herinis (Santorin) to Crete.

To my regret, I have been unable to pursue this quest further, either by inquiry on the spot or in libraries, except in regard to the names of these Cretan children (cf. pp. 246, 250).

I will conclude this part of the discussion with the mention of a fact that struck me very forcibly in the Balkans—viz., the great similarity in bearing and character that (to my mind at least) exists between the Montenegrins and the Cretans of Sitia (province). If correct, this would provide additional support to the view that South Slavonic elements are to be looked for in modern Cretans; and herein lies an explanation of the marked contrast, in respect of skull-form, between the prehistoric and historic inhabitants of the island.

VI. *Variability in head-length, head-breadth, and cephalic index (in Cretans).*—The calculation of the value of the standard-deviation for three characters is given in Table V., with some comparable data for other groups and nationalities. Here it must suffice to remark that the value of the standard-deviation of the cephalic index in the Cretan boys measured by me does not greatly differ in value (4·8 for seventy-nine boys) from the figures (4·1) provided by Mr. Hawes [6] for the 1,600 adult Cretan men measured by him. But both young and adults provide figures indicative of a relatively high degree of variability, and indeed the contrast between, for instance, Sitia and Selino in respect of the mean value of the cephalic index has already emphasised this point. It will

[1] Noiret, *op. cit.*, p. 322.
[2] Noiret, *op. cit.*, p. 36.
[3] Noiret, *op. cit.*, p. 225.
[4] Noiret, *op. cit.*, p. 264.
[5] Noiret, *op. cit.*, p. 545.
[6] *British Assoc. Report*, 1908.

be noticed that the Cretan boys are more variable than the men (4·8 for the boys as against the 4·1 for the men). Herein a general rule (formulated as the results of many hundreds of observations by Roberts, Boas, and Bowditch) appears to apply to Crete as well as to England and the United States.[1]

TABLE V.

—	Dimension	Age (Mean)	No. of Examples	Mean	Prob. error of Mean	σ	Prob. error of σ	C	Prob. error of C.
	Head-length.								
1	Cretan Schoolboys .	(9·9)	79	173	0·508	6·67	0·353	3·85	0·206
2	Aragonese Schoolboys .	(8·5)	100	178	0·354	5·25	0·246	2·95	0·140
	Head-breadth.								
1	Cretan Schoolboys .	(9·9)	79	140	0·504	6·65	0·352	4·75	0·254
2	Aragonese Schoolboys .	(8·5)	100	138	0·285	4·23	0·198	3·07	0·146
	Cephalic Index (on living).								
1	Cretan Adults (Hawes) (Males)	—	1600	79	0·069	4·1	0·048	5·2	0·062
2	Cretan Schoolboys .	(9·9)	79	81	0·360	4·8	0·254	5·92	0·317
3	Aragonese Schoolboys .	(8·5)	100	78	0·189	2·81	0·132	3·6	0·171
4*	British Boys (Herts) .	(8 to 14)	57	78	0·285	3·20	0·201	4·1	0·258
5†	British Boys (Beddoe) .	(16)	200	78	0·128	2·70	0·089	3·45	0·116
6‡	American Schoolboys .	(9)	135	80	0·216	3·74	0·153	4·675	0·191
7‡	American Schoolboys .	(5 to 13)	1003	79	0·068	3·44	0·051	4·3	0·064
8§	North African Jewish Boys	(6 to 16)	606	78	0·083	3·08	0·059	3·93	0·075

* From measurements by Messrs. Cooper and Ward (unpublished).
† From measurements recorded by Beddoe (*Journ. Roy. Anth. Instit.*, vol. xxxiv., 1904, p. 92).
‡ From measurements recorded by West (*Archiv. für Anthr.*, Band xxii).
§ From measurements recorded by Fishberg (*Boas Memorial Volume*).

B.—*CRETAN SCHOOLGIRLS* (*ages from* 5 *to* 11 *years, the mean value being* 7·7 *years*).

Twenty-five Cretan girls were examined at Vori, none being available at Palaikastro. The observations have been summarised in the order following:—

TABLE VI.—*Hair-colour and Age.*

Twenty-five Cretan Schoolgirls. (Mean Age 7·7 years.)						
Colour	No.	Per Cent.	Mean Age	Colour	Per Cent.	Mean Age
Fair . .	12	48	7·91 years	Light	52 (Boys, 32·76)	7·7 years (Boys, 8·92 ,,)
Light brown	1	4	6·00 ,,			
Brown .	8	32	8·12 ,,	Medium	32 (Boys, 22·68)	8·12 ,, (Boys, 9·9 ,,)
Dark brown	4	16	6·50 ,,	Dark	16 (Boys, 44·1)	6·5 ,, (Boys, 10·62 ,,)

[1] Cf. the tables collected by Jenkinson in his *Experimental Embryology*, Oxford, 1909, p. 73.

The smaller number of examples is accountable for the lack of distinctness in the association of age and hair-tint. I have no doubt but that a longer series would show clearly that, as among the boys, the hair darkens with age. Probably, also, the condition observed in this country would also obtain—viz., that in the female sex the darkening never becomes so marked as in the male. It is a matter for speculation whether exposure to the open air has an influence here.

As regards the association of eye-colour with hair-colour, the records show that dark-brown hair is never accompanied (in this series) by eyes of lighter tint, although fair hair (especially, of course, in the younger girls) may be found with dark eyes.

II. The records of eye-colour have been summarised as follows:—

TABLE VII.—*Eye-colour and Age.*

Twenty-five Cretan Schoolgirls. (Mean Age 7·7 years.)						
Colour	No.	Per Cent.	Mean Age	Colour	Per Cent.	Mean Age
Blue	1	4	11 years	Light	8 (Boys, 17·5)	8·5 years (Boys, 10·2 ,,)
Grey	1	4	6 ,,			
Green	1	4	13 ,,	Medium	40 (Boys, 25·0)	8·0 ,, (Boys, 10·5 ,,)
Hazel	8	32	7·5 ,,			
Medium brown	1	4	7 ,,			
Dark brown	13	52	7·3 ,,	Dark	52 (Boys, 57·5)	7·3 ,, (Boys, 9·6 ,,)

The inspection of this table shows that the association of eye-tint and age is just as indefinite as among the boys. As in the case of the hair, we find here reason to suppose that the depth of pigmentation is less in the female sex. There may be a real sexual difference here, or the result may be simply due to the more constant exposure of the males (whether boys or men) to the weather; and I incline to lay stress on the latter consideration.

III. *Head-length.*—The mean value of this dimension in 25 girls (at Vori), of an average of 7·7 years, is 166·8 mm. Fifty-nine boys at Vori provide an average of 173·9 mm., but the mean age of the boys was 9·9 years. We have seen that nine boys of a mean age of 6 years gave an average measurement of 171 mm. Evidently the female head is smaller in this dimension.

IV. *Head-breadth.*—The mean value of this dimension in 25 girls (at Vori) is 133·7 mm. The boys at Vori (59 in number) gave an average of 139·3, but their age is greater. Nine boys averaging 6 years of age give a mean value of 135·4. From all this it appears that in childhood the female head is less broad than the male.

V. *The Cephalic or Breadth-index.*—The mean value of this index in 25 girls (at Vori) is 80·1. Boys with a mean age of 6 years provide a mean index of 79·2. All the boys taken together give 80·9 as the mean value. So far, then, it does not seem as though the sexual difference

were marked in this respect, though the female head seems rather more brachycephalic. One girl, however (No. 6), having an index of 94·9, has had a very appreciable effect in raising the average of this series of twenty-five individuals.

VI. Before passing from the consideration of this index, I would remark that in eleven girls (out of twenty-five) the maximum length of the head will be found actually between an ophryonic point and an occipital point. The same occurrence was noted in the boys (cf. p. 247). The indices here employed have been based on the glabello-occipital length. But if we employ the real maximum in the cases in which it was not glabello-occipital, we can calculate a cephalic index which will clearly provide lower numerical (*i.e.*, more dolichocephalic) results than those just described. For this purpose I have data from the following groups:—

TABLE VIII.—*Cephalic Index, calculated not from the glabello-occipital length, but from the maximum length, even when this is measured high above the glabello, the forehead being then bombé, as the French writers describe it.*

Group.	No.	Index
(*a*) Boys at Vori	(14)	78·9
(*b*) Girls at Vori	(11)	78·7
(*c*) Cretan boys in general	(23)	80·7
(*d*) Boys at Palaikastro	(9)	83·4

The similarity between boys and girls at Vori, and the independent position of the Palaikastro (*i.e.*, eastern) group come out here very clearly.

The final tables include the whole of the detailed data whence the foregoing summaries have been made. I have also appended a list of the names of the individuals. The chief interest herein will lie in the search for names suggestive of a Venetian or other exotic provenance. Dr. Gerola provides a long list of the names of the Venetian families of Crete.[1] Looking through my list and that of Dr. Gerola, I find very few names in my collection capable of being claimed as Venetian. Of the boys, No. 23, Frangoulakis, may represent Dr. Gerola's family, Franco; and Kondourakis may be derived from Contarini. Nos. 30, 35, 42, 49, and 53 all bear the name Zorzakakis; this almost certainly represents the family Zorzi, mentioned by Dr. Gerola, No. 48A. Zangarakis may represent the name Zangarol. The girls provide no other names needing mention here.

[1] Cf. Gerola, *Monumenti Veneti nell' Isola di Creta*, 1905, p. xlix. Camb. Univ. Lib., Lib. 2, 90, 152.

TABLE IX.—*Cretan Schoolboys at Vori* (59).

Locality and Number	Age	Maximum Head-length from Glabella	Head-breadth	Cephalic Index	Maximum Head-length Fronto-occipital when not Glabello Occipital	Corresponding Cephalic Index
Vori No.						
1	6	165	131	79·4	—	—
2	8	172	134	77·9	—	—
3	8	156	139	89·1	—	—
4	7	175	135	77·1	—	—
5	8	173	140	80·9	—	—
7	9	160	143	89·4	—	—
8	9	166	134	80·7	—	—
9	8	180	130	72·2	—	—
10	8	175	140	80	—	—
11	15	180	146	81·1	—	—
12	11	183	134	73·2	—	—
13	7	166	152	91·6	—	—
14	8	172	140	81·4	—	—
15	11	177	134	75·7	—	—
16	11	180	140	77·8	—	—
17	11	177	141	79·7	—	—
18	11	170	137	80·6	—	—
19	10	173	139	80·3	—	—
20	10	179	141	78·8	—	—
21	10	171	140	81·9	—	—
22	12	187	137	73·3	—	—
23	10	176	132	75	—	—
24	16	173	144	83·2	—	—
25	13	172	142	82·6	—	—
26	13	185	142	76·8	—	—
27	13	171	142	83	—	—
28	10	175	140	80	—	—
28*a*	12	171	157	91·8	—	—
29	12	178	135	75·8	—	—
30	11	186	144	77·4	—	—
31	12	177	136	76·8	—	—
32	10	183	138	75·4	—	—
33	15	184	130	70·7	—	—
34	12	180	155	86·1	—	—
35	13	178	154	86·5	—	—
36	14	171	141	82·5	—	—
37	14	186	150	80·6	—	—
38	15	182	151	83	—	—
39	6	178	136	76·4	—	—
40	10	175	141	80·6	—	—
41	6	182	137	75·3	—	—
42	7	163	142	87·1	168	84·5
43	7	166	142	85·5	173	82·1

TABLE IX.—*Cretan Schoolboys at Vori* (59) (continued).

Locality and Number	Age	Maximum Head-length from Glabella	Head-breadth	Cephalic Index	Maximum Head-length Fronto-occipital when not Glabello Occipital	Corre-sponding Cephalic Index
Vori No.						
13*a*	7	169	129	76·3	—	—
44	9	179	143	79·9	182	78·6
45	8	171	146	85·4	179	81·6
46	5	177	146	82·5	182	80·2
47	7	175	132	75·4	177	74·6
48	7	168	134	77	174	79·8
48*a*	7	176	137	77·8	182	75·3
48*b*	8	168	139	82·7	—	—
49	9	166	137	82·5	168	81·5
50	10	170	132	77·6	—	—
51	10	177	141	79·7	181	77·9
52	6	167	137	82	174	78·7
53	6	173	129	74·6	175	73·7
54	5	166	135	81·3	—	—
55	5	166	135	81·3	171	78·9
56	6	165	133	80·6	171	77·8
Palai-kastro No.						
1	8	168	141	83·9	—	—
2	10	168	141	83·9	—	—
3	7	172	148	86	—	—
4	8	169	135	79·9	—	—
5	9	159	152	95·6	—	—
6	12	170	135	79·4	—	—
7	13	176	153	86·9	—	—
8	13	177	140	79·1	—	—
9	13	172	149	86·6	174	85·6
10	11	175	155	88·6	179	86·6
11	11	164	143	87·2	165	86·7
12	12	168	131	78	—	—
13	13	176	137	77·8	180	76·1
14	13	183	152	83·1	187	81·3
15	10	166	144	86·7	168	85·7
16	13	178	150	84·3	182	82·4
17	16	180	140	77·4	—	—
18	13	172	141	82	175	80·6
19	10	162	141	87	164	86
20	7	169	132	78·1	—	—

TABLE X.—*Cretan Schoolgirls at Vori.*

No.	Age	Hair-colour	Eye-colour	Head-length	Head-br'dth	Cephal' Index
1	7	Fair	Dark brown	162	138	(85·2)*
2	11	Fair	Blue	175	139	79·4
3	8	Brown	Dark brown	161	130	80·7
4	11	Fair	Hazel	169 (172)†	136	80·5 (79·1)†
5	9	Fair	Dark brown	172 (175)	139	80·8 (79·4)
6	9	Dark brown	Dark brown	155 (157)	149	96·1 (94·9)
7	13	Brown	Green	170	140	82·4
8	6	Fair	Hazel	162 (169)	129	79·6 (76·3)
9	6	Fair	Grey	168	138	82·1
10	10	Fair	Dark brown	173 (177)	130	75·1 (73·4)
11	8	Brown	Dark brown	168	130	77·4
12	7	Brown	Hazel	160	136	85
13	11	Fair	Hazel	173 (176)	135	78 (76·7)
14	6	Fair	Hazel	167 (172)	132	79 (76·7)
15	6	Brown	Hazel	170 (173)	137	80·6 (79·2)
16	5	Fair	Dark brown	170 (173)	141	82·9 (81·5)
17	5	Dark brown	Dark brown	168 (175)	132	78·6 (75·4)
18	7	Brown	Hazel	169	126	74·6
19	6	Light brown	Hazel	170	134	78·8
20	6	Dark brown	Dark brown	160	140	87·5
21	6	Fair	Dark brown	167	128	76·6
22	6	Dark brown	Dark brown	169	125	74
23	8	Brown	Dark brown	166	128	77·1
24	7	Fair	Dark brown	164	130	79·3
25	7	Fair	Medium brown	162	131	80·9
26	8	Brown	Dark brown	167 (177)	129	77·2 (72·9)
Average (excluding No. 1)	7·7			166·8	133·7	80·16

* Epirote, and therefore excluded.

† The figures in brackets are the maximum fronto-occipital head-length, and the cephalic index derived from this. Corresponding values for boys are given in Table IX.

TABLE XI.—*Cretan Schoolboys* (79 *or* 80).*

Eye-colour, Light (Blue, Grey, Grey-green)				Eye-colour, Medium (Green, Light Brown, Hazel, Medium Brown)				Eye-colour, Dark (Dark, Dark Brown, Very Dark Brown, Jet Black)			
Very Fair, Fair, Light Brown	Brown	Dark, Dark Brown, Black	Jet Black	Very Fair, Fair, Light Brown	Brown	Dark, Dark Brown, Black	Jet Black	Very Fair, Fair, Light Brown	Brown	Dark, Dark Brown, Black	Jet Black
10 12·50%	0 0	4 5·0	0 0	9 11·25	5 6·25	4 5·0	2 2·50	7 8·75	13 16·25	23 28·75	3 3·75
Aragonese Schoolboys (99 *or* 100).*											
5 5·05%	5 5·05	3 3·03	0 0	11 11·11	20 20·20	14 14·14	1 1·01	9+1 red 9·09	6 6·06	18 18·18	6 6·06

* One Cretan boy had eyes of different colours, and for the purpose of colour

TABLE XII.—*Indices, Hair- and Eye-colour.*[1]

—	—	Crete	Aragon	—
1	Eyes. Beddoe's Index (D—L)	+40	+27·27	(cf. 351 British=+3·4)
2	Hair. Beddoe's Index (D+2B—R—F)	+25	+23·23	(cf. 351 British=—38·74)
	Eyes and Hair Combined:			
3	Beddoe's Compound Index	+90	+73·27	(cf. Dalmatia: mean 108) Range 54—156
4	Collignon's Compound Index	+26·25	+22·22	(cf. 351 British=—17·8)
5	Freire-Marreco's Compound Index	452·5	424·2	(cf. mean for 7 British localities=363·9)

TABLE XIII.—*Names of Cretan Schoolboys at Vori, Crete.*

1. Miron Capellakis.
2. Pavlos Skordhalakis.
3. Constantinos Nicolidhakis.
4. Pavlos Polydhakis.
5. Joannis Nicolidhakis.
6. Phortios Phortiádhes, an Epirote boy. See Girl No. 1.
7. Georgios Papadhakis.
8. Manoli Kamarianakis.
9. Nicolaos Kadhianis.
10. Evangelos Makridhakis.
11. Nicolaos Mproulidhakis.
12. Michael Jannakakis.
13. Charalampos Kapelakis.
14. Evangelos Mytolidhakis.
15. Joannis Mylonakis.
16. Georgios Georgolakis.
17. Georgios Papadhakis.
18. Joannis Rethymolakis.
19. Georgios Skordhalakis.
20. Georgios Kourmoulakis.
21. Evangelos Polydhakis.
22. Elias Kamarianakis.
23. Joannis Frangoulakis.
24. Evangelos Makrydhakis.
25. Elias Erygakis.
26. Joannis Nicolidhakis.
27. Georgios Kotsfakis. (? Kontsifakis).
28. Charalampos Dhoulzierakis.
29. Nicolaos Polychronakis.
29*a*. Joannis Polydhakis.
30. Michael Zorzakakis.
31. Nicolaos Milonakis.
32. Michael Melonidhakis.
33. Joannis Sabbakis.
34. Georgios Joseph Skordhalakis.
35. Georgios Zorzakakis.
36. Emmanuel Piperakis.
37. *Constantinos Voleykronakis.*
38. Georgios Fitsodhaskalakis.
39. Joannis Kondourakis.
40. Manolis Xenogianakis.
41. Michael Papadhakis.
42. Manolis Zorzakakis.
43. Stylianos Piperakis.
43*a*. Michael Milonakis.
44. Michael Xenakis.
45. Georgios Askoxylakis.
46. Stavros Skordhalakis.
47. Antonios Stavrolakis.
48. Demosthenes Polychronakis.
48*a*. Georgios Zangarakis.
48*b*. Georgios Polydhakis.
49. Georgios Zorzakakis.
50. Michael Georgolakis.
51. Nicholaos Kondourakis.
52. Stavros Polydhakis.
53. Georgios Zorzakakis.
54. Grergorios Nicolidhakis.
55. Evangelos Grigorakis.
56. Manolis Makrydhakis.

statistics was counted in twice (making a total of 80 in this case); one eye was light while the other was dark. Among the Aragonese, one eye-record (No. 20) was not taken, so that the numbers are either 99 or 100 accordingly.

[1] Reference for comparisons should be made to Dr. Beddoe's lecture on 'Colour and Race,' published in the *Journal of the Royal Anthropological Institute*, vol. xxxv., 1905; also to Miss Freire-Marreco's valuable paper on 'The Hair and Eye-colour of 591 children of School Age in Surrey,' published in *Man*, 1909, 63. The British records in Table XII. are taken from the latter paper.

Names of Cretan Schoolboys at Palaikastro, Crete.

1. Georgios Mavrokoukoulakis.
2. Gregorios Papadhakis.
3. Konstantinos Avronidhakis.[5]
4. Georgios Bonatsakis.
5. Georgios Relakis.
6. 'Christos' Christodhoulakis.
7. Konstantinos Ailamakis.
8. Nikolaos Christodhoulakis (brother No. 6).
9. Pandelis Gorbadzakis.
10. Joannis Mavrokoukoulakis.
11. Gregorios Brylakis.
12. Konstantinos Avronidhakis.[1]
13. Nicholaos Stephanakis.
14. Manoel Tsandhakis.
15. Manoel Bonatsakis.
16. Joannis Xipolitakis.
17. Joannis Gremiakis (Jeremiakis).
18. Emmanoel Tsimitakis.
19. Konstantinos Scaromariolakis.
20. Gregorios Mavrokoukoulakis.

Names of Cretan Schoolgirls at Vori, Crete.

1. Andronike Phortiádes (Epirote—see boy No. 6).
2. Eirene Nicolitakis.
3. Ourania Kontsifakis.
4. Aristea Zorzakakis.
5. Katina Papadhakis.
6. Elene Mpistogianakis.
7. Marianthi Askoxylakis.
8. Elene Pitharakis.
9. Chrysanthi Polydhakis.
10. Pagona Papadhakis.
11. Chrysanthi Papadhakis.
12. Marigo Kardhianis.
13. Evangelia Nicolidhakis.
14. Kallirhoe Makridhakis.
15. Andronike Amargiolakis.
16. Kalliope Kapellakis.
17. Eugenea Miserlakis.
18. Asymenia Mproulgidhakis.
19. Elene Zorzakakis.
20. Evangelia Askoxylakis.
21. Evangelia Dhendhrakis.
22. Kyriakis Xenogianakis.
23. Angelike Frangoulakis.
24. Evangelia Krasadhakis.
25. Elene Makridhakis.
26. Elene Gianakakis.

APPENDIX III.

Some Remarks on Dr. Duckworth's Report (Appendix II.).

By CHARLES H. HAWES.

The point I wish to remark upon in Dr. Duckworth's paper is the suggestion that the Venetian occupation of Crete is to be held accountable for the broader heads of the Sitians in Crete.

But before taking this up I should like to mention that, outside of the Venetian question, my large mass of figures in the main bears out Dr. Duckworth's results. To his data for hair-colour, and his remark on the absence of red hair, I may add that out of 2,000 children observed by me, 10 had red hair, and of 2,488 men 11 were red-headed—a proportion of half, and less than half per cent. Also, while the age independence of eye-colour compared with hair-colour is marked, it is not absolute. I could find no change through the periods of adolescence and maturity save one. Certainly there was no darkening tendency, but rather the opposite, in the case of some dark eyes. This class of eye is perhaps best described as *foncé*; it is bafflingly opaque, and this tempts one to label it black, but no one who has seen the black eye of a Negrito would do so. This eye changes in many cases, not in all, at puberty or before, into a dark-brown or even brown eye.

Turning to the Venetian question, I agree most heartily with Dr. Duckworth that the history of the Venetian occupation of Crete would well repay study, and it is to be regretted that no English student has yet extracted it from the archives of Venice.

[1] Possibly Mavronidhakis.

Dr. Duckworth suggests that the broader heads of the Sitians, as compared with their neighbours of Central Crete, are due to the Venetians and their levies of Dalmatians and Illyrians. I have hinted that this broadening influence may come from Asia Minor.

The best test that we can apply to Dr. Duckworth's theory is to select Cretans of to-day bearing Venetian names, and compare them anthropometrically with the peoples of Venetia, Dalmatia, and Illyria. It is by no means an easy task to decide which are Venetian names under their Cretan disguise; and, again, a name which looks Italian may have a similar derivation in both Greek and Latin. But there are certain well-known Venetian names, such as Cornaro, Dandolo, Dafermo, Modano, Kallergi, Markantonio, and Renero, which may be easily recognised. Examples of others which appear among Cretan cognomens to-day, but which are not so familiar, at any rate in their Cretan dress, are Kavvalos, Maniadhes, Perakis, Printalos, Saloustros, Soultatos, and Frantzeskos. For many of these I am indebted to Mr. Xanthoudides, the Assistant Ephor of Antiquities at Candia. Perhaps in all I have recognised about 70 different Venetian names. There are possibly more which might yield to a close philological study, and perhaps some additions from these should be made to my totals. Out of a total of 2,298 Cretan men measured throughout Crete by me, 150 bore Venetian names, *i.e.*, 6½ per cent. If we make further additions, I do not think that this figure would exceed 8 per cent. I believe that my figures fully represent the case. Mr. Xanthoudides was good enough to go through the lists of voters of several demes with me, selecting Venetian names, and in comparing the most populous deme I find that my proportion of Venetian names in that deme among the measured is 11½ per cent. more than the proportion among the voters, showing that I had cultivated, or happened upon, the Venetian element. Such a comparatively high percentage will cause surprise when we consider the history of the Venetian occupation, the dislike of the Venetian settlers for a country life among a hostile people continually given to revolution, their desertion of their estates for a city life, a process hastened by the long sieges of Canea and Candia, and the ultimate surrender and withdrawal. If we want to get an idea of the process, we have only to turn to Crete to-day, where we may see it going on, only under a peaceful guise. The Mussulmans, who numbered 73,234 in 1881, had dwindled in 1900 to 33,496, and in 1910 they have probably lost another 50 per cent. In 1881 they occupied farms in the country districts in their thousands, as the census shows. By 1900 these thousands had fled to the seaport towns and to Asia Minor, leaving but a few hundreds in the country regions, mainly within a few hours' ride of Candia. And the steady flight continues; so that, were Crete given up to Greece, there is no doubt that the Mussulmans, though mainly of Cretan blood, would leave but a few hundreds to represent the Turkish occupation of the island.

It is, therefore, somewhat surprising to find, on estimate, that there are perhaps 20,000 out of 300,000 Cretans with Venetian names. The late Dr. Jannaris, the well-known philologist, would admit to me no claims of Cretans to Venetian descent outside of the three or four well-

known families in the cities, and recalling the Cretan fondness for giving nicknames, attributed such names as Venetikos to this habit, the labelling of a native servant with the cognomen of his master's nationality. Mr. Xanthoudides remarked to me that half the names in the Cretan villages were Venetian, but that they meant nothing. The former part of Mr. Xanthoudides' statement was not borne out by reference to the voters' list, *i.e.*, in the names of those over twenty-one years. In the more favourable districts the percentage was 13.

More important for us than these corrections is the consideration that a Venetian name in Crete connotes very little Venetian blood. Nearly nine generations have passed since the Venetians left the island, and their blood must be very thin or bred out by this time, and, what is important to note in this connexion, the national or racial consciousness that would dictate a marriage of Venetian-named with Venetian-named is lost. In the one village in Crete that bears the reputation of being a Venetian colony, Axos, the people were ignorant that they bore Venetian names, and resented the imputation—having, perhaps, a folk-memory of those hard taskmasters, whom their forefathers hated more than the Turks. Those who are sophisticated and well-read among the Venetian-named, such as the local antiquary and justice of the peace at Vitzari, in Amarion, a Siligardi by descent; the scholarly Archimandrite Veneris; the prosperous merchant of Xidhas, Kandherakis, whose great desire to have Lyttos excavated is now to be fulfilled; or the most successful and intelligent carpenter of Candia, Cornaro, can only point to some one far-distant ancestor or to family tradition. Thus, while the years and centuries have gone by, the blood has decreased, and only the names have remained, or even increased with the increase of the population.

But, to turn from general considerations, if we are to attribute, as Dr. Duckworth does, the broadening of the head in Sitia to the Venetian influence, we should expect to find that influence most active and more apparent where the Venetian-named Cretans are thickest. This area is the Deme of Anogeia, in which Axos, with some seven other villages, is situate. Out of 175 names (borne by 992 voters, and representing a population of 4,054), 41 (or 23½ per cent.) are Venetian, and out of 69 measured by me in this deme, 24 (or 35 per cent.) are Venetian in name; an extraordinary average compared with 5½ per cent. for the rest of the island. I may note here that the figures I shall quote for the eparchies take account only of the names recognised as Venetian, and do not include additions for doubtful names. How do these Venetian-named individuals compare in cephalic index with the modern Venetians and their neighbours? The cephalic index of the people of Veneto-Emilia (52,410, quoted by J. Deniker) is 85·1, of Dalmatians (30, by J. Deniker) 87·0, of Albanians (20, by Pittard) 83·8. That of the Venetian-named Cretans in their most populous region is 76·7. This figure needs no comment of mine.

Let us turn to Sitia itself, where there are 10½ per cent. of Venetian names. This percentage is not extraordinary, being exceeded by four other eparchies. The average cephalic index for 189 Sitians, including Dr. Duckworth's figures, is 80·9, or nearly 81·0, to be accurate, that of the Sitians bearing Venetian names is 81·3. This suggests the key

to the situation, for we shall find, on comparing the average cephalic index of the Venetian-named and that of the eparchy in which they are located, that in several cases there is close agreement, and most important of all in the grand totals. Where there are variations, they seem to be due to small numbers; and the lowering of the index is more pronounced than the heightening. The following are examples:—

Eparchy	Percentage of the Venetian-named	Cephalic Indices	
		Whole eparchy	Venetian-named
Ierapetra . . .	8·6	79·6	79·1
Kisamos . . .	6·8	79·4	79·3
Mylopotamon . .	22·9	77·9	76·9
Selinon. . . .	11·6	80·9	77·5

The most important evidence is obtained in the comparison of the totals. The average cephalic index of the 150 Venetian-named individuals, measured throughout Crete by me, is 79·0, which is the exact figure mentioned in my previous paper for the whole of Crete (2,290 individuals).

What is the conclusion to which we are drawn? That the Venetian strain has remained strong and powerful after nine generations without replenishment from the mother country? Scattered through the land, its consciousness of nationality lost, has it not bred out? Where is the Venetian brachycephal or hyper-brachycepal in the most populous of Venetian districts in Crete? What is the dictum of the other eparchies, and what of the whole? They are unaffected by the Venetian element. Where people are dolichocephalic, the Venetian-named among them are dolichocephalic, and where they are mesaticephalic, there the latter are mesaticephalic also.

I need not labour this point. The Venetians are not the determining element, but the determined. Therefore it is that in my report, taking a large view of Cretan ethnology, I treated the Venetian element as negligible.

But what, then, is the cause of the broadening of the head in Sitia? Must we leave it unexplained? I think not. Crete is linked up by the stepping-stones of Karpathos and Rhodes to Asia Minor. Sponge-divers from the Asia Minor coast are found off Sitia to-day. Dr. Duckworth mentions the Turks marauding and settling, even during the Venetian occupation, in 1417 and 1471, and no doubt it would be possible to extend these connections back to Minoan times, when, as Mr. Hogarth found, the little town of Zakro imported from Asia Minor. The connection is natural and historical, and, for the matter of that, pre-historical.

Has anthropometry anything to confirm this? Let us see.

I have called attention in my previous paper to the fact that the Sitians in the extreme east of Crete, and the Selinots in the extreme west, have the same cephalic index—namely, 80·9, but that there is this difference: that the Selinot is broad-headed and the Sitian is short-headed.

Now, if we turn to Asia Minor, we shall find that it is a region of short-headedness.

For purposes of comparison, as we have a long-headed population in Crete, we will extract the brachycephals of Crete and compare them with peoples in Asia Minor. This gives us 71 brachycephalic Sitians, whose measurements, compared with those of Turks and Tachtadshy (Takhtadji) of S.W. Asia Minor are as follows:—

—.	Number	Head Length	Head Breadth	Cephalic Index
Sitians of Crete . .	71	180·1	153·2	85·1
Turks of Asia Minor (Chantre)	120	181·0	153·0	84·5
Takhtadji (Petersen and von Luschan)	13	178·8	153·2	85·7

Chantre's 297 Armenian men have a cephalic index of 85·5; head-lengths and head-breadths I cannot give, as I write without books of reference by me.

One could hardly demand a closer agreement than with these figures of 120 Turks and 13 Takhtadji, those wild peoples of the marshes and uplands of Asia Minor, who, in the opinion of von Luschan, best represent the prehistoric race of Asia Minor. As we get further away from the Aegean to Lake Van and Russian Armenia, the head is even shorter, but also rather broader (27 Aissori, 22 males and 5 females, are 173 mm. long and 155 mm. broad). This may be the result of deformation, but in any case our connections are naturally nearer at hand.

Now let us try Veneto-Emilia, Dalmatia, and the Illyrian area. [And here I much regret that I am without reference books, and must depend on odd notes.]

The cephalic index of 30 Dalmatians (Deniker) is 87·0, and that of 52,410 inhabitants of Veneto-Emilia is 85·1.

Unfortunately, I cannot give the head-lengths and head-breadths of these, but from 18 Venetian soldiers measured by me I have the following:—

Head Length	Head Breadth	Cephalic Index
185·1	155·2	83·9

and for Pittard's 20 Albanians we have the following:—

Head Length	Head Breadth	Cephalic Index
185·0	155·7	83·8

These figures, which represent not a *short* head but a *broad* head, compare with the Selinots in the western end of Crete, the brachycephals among whom, to the number of 33, have the following:—

Head Length	Head Breadth	Cephalic Index
185·3	157·5	85·0

and I may remind my readers that in my previous reports I have derived this western Cretan brachycephal from the north, and ultimately from Illyria.

It might be thought that with such a notable stature on the part of the Dalmatic and Illyric people, this feature alone ought to settle the whole question. It certainly is more than confirmatory, although one has to be careful in using statistics of stature, a feature which is far less permanent than head form. The Sitian brachycephal has a stature of 1,678 mm.; the stature of the brachycephalic Takhtadji is 1,679 mm.; of 287 Armenians (Chantre), 1,680 mm.; of 18 Armenians from Lake Van, measured by me, 1,678 mm. That of the Turks varies from 1,710 mm. (120 measured by Chantre) to 1,670 mm. (recorded by Elysieff).

The stature of Albanians awaits further measurements, for Pittard gives the low figure of 1,674 mm. (for 20 individuals), against mine, 1,777 mm. for 28 measured in Martino. But we are on safer ground with the Dalmatians (325 individuals), 1,715 mm., and Montenegrins, 1,711 mm. These are 33-37 mm. taller than our Sitians, but approximate to the stature of our brachycephalic Selinots (1,701 mm.), and their neighbours the Sphakiots (1,710 mm.).

Archæological Investigations in British East Africa.—Interim Report of the Committee, consisting of Mr. D. G. Hogarth *(Chairman)*, Dr. A. C. Haddon *(Secretary)*, Mr. H. Balfour, Mr. C. T. Currelly, Dr. H. O. Forbes, *and* Professor J. L. Myres.

The Committee appointed to report upon Archæological Investigations in British East Africa obtained information from Mr. C. W. Hobley and other sources concerning the caves on Mount Elgon and in the scarps of the Rift Valley, and from Mr. A. C. Hollis on the ancient graves on the sea coast of British East Africa. These two gentlemen and Mr. E. B. Haddon have also supplied valuable information concerning the equipment and method of conducting expeditions for carrying out these important investigations. When the Committee were appointed it was expected that more than one member of the Committee would undertake this work, but circumstances have since arisen which make this impossible. The information now gathered together is available should a British expedition be undertaken in future. In the meantime the Committee do not seek reappointment.

Anthropometric Investigation in the British Isles.—Report of the Committee consisting of Professor Arthur Thomson *(Chairman)*, Mr. J. Gray *(Secretary)*, *and* Dr. F. C. Shrubsall.

The Committee take this opportunity of recording the great loss they have sustained by the death of Professor D. J. Cunningham, who was Chairman of the Committee from 1903 to 1909, and in that capacity rendered inestimable services to anthropometric investigation.

During the past year, anthropometric investigation has been making steady, though as yet somewhat slow, progress in the British Isles.

Under recent Acts of Parliament measurements of height and weight are being extensively carried out in primary schools in England and Scotland, and numerous inquiries have been received from medical officers and others as to the best methods of making these measurements. The Committee have been able to refer them to the report on anthropometric method published by the Royal Anthropological Institute. It is satisfactory to note that the sale of this report is steadily increasing.

The Committee are pleased to note that an Anthropometric Bureau has been installed at the Japan-British Exhibition, under the supervision of the Royal Anthropological Institute, and hope that means will be found of making such a bureau a permanent institution.

The Committee are making arrangements, in co-operation with other agencies, to have measurements made of the adult rural population of the British Isles.

Applications have been received for information about methods of measurement from many parts of Greater Britain, as, for example, Cyprus, Australia, and New Zealand.

Anthropometric Committees have been formed or are being formed in many foreign countries, among which are Germany, Denmark, and Norway. The Danish Committee have already published some very valuable reports on the physique of children and adults in Denmark.

The Immigration Commission of the United States of America have been carrying out under the direction of Professor Franz Boas anthropometric investigations on immigrant races, coming from all parts of Europe, with the view of ascertaining the changes produced by the American environment. A copy of Professor Boas' valuable report has been presented to the Committee through the Privy Council by the U.S. Government. The Committee ask to be reappointed with a grant of *5l.* to cover expense of correspondence, &c.

Anthropological Photographs.—Report of the Committee consisting of Dr. C. H. Read (*Chairman*), Mr. H. S. Kingsford (*Secretary*), Dr. G. A. Auden, Mr. E. Heawood, *and* Professor J. L. Myres, *appointed for the Collection, Preservation, and Systematic Registration of Photographs of Anthropological Interest.*

The Committee have to report that, in pursuance of a resolution passed by the Council of the Association, the collection of photographs has been deposited at the Royal Anthropological Institute, where it is now available for purposes of reference and study.

The Committee have also to report that, owing to the initiative of Mr. N. W. Thomas, M.A., Government Anthropologist, Southern Nigeria, officers in the West African service will be asked to register with the Committee any photographs taken by them, and where possible to deposit prints in the collection. No additions have been made to the collection this year.

The Lake Villages in the Neighbourhood of Glastonbury.—Report of the Committee, consisting of Dr. R. MUNRO (*Chairman*), Professor W. BOYD DAWKINS (*Secretary*), Professor W. RIDGEWAY, *and* Messrs. ARTHUR J. EVANS, C. H. READ, H. BALFOUR, *and* A. BULLEID, *appointed to investigate the Lake Villages in the neighbourhood of Glastonbury in connection with a Committee of the Somersetshire Archæological and Natural History Society.* (*Drawn up by* Messrs. ARTHUR BULLEID *and* H. ST. GEORGE GRAY, *the Directors of the Excavations.*)

THE Committee report that the large and exhaustive monograph describing the Glastonbury Lake Village is now approaching completion. The work will be issued privately by the Glastonbury Antiquarian Society, and will consist of two royal quarto volumes; an illustrated prospectus has recently been circulated, and copies may be obtained on application. Vol. I. will be published during the latter part of this year, or in the early part of 1911. The work for Vol. II. is also well in hand, and will be issued as soon as possible after Vol. I.

The results of the tentative explorations in 1908 of the Lake Village at Meare were of so important and encouraging a nature that the matter was at once taken up by the Somersetshire Archæological and Natural History Society,[1] but owing to the large amount of work to be accomplished for the publication of the monograph on the Glastonbury Lake Village, it was deemed advisable to postpone the further examination of the Meare site until 1910. The first season's systematic digging opened on May 23 and continued for three weeks, excluding the week devoted to filling in the area dug. Although it had been previously arranged to dig for the short period mentioned, all further work would, however, have been effectually stopped by heavy rain had there been any intention of working for a longer period, for the River Brue was overflowing and the adjoining fields were under water.

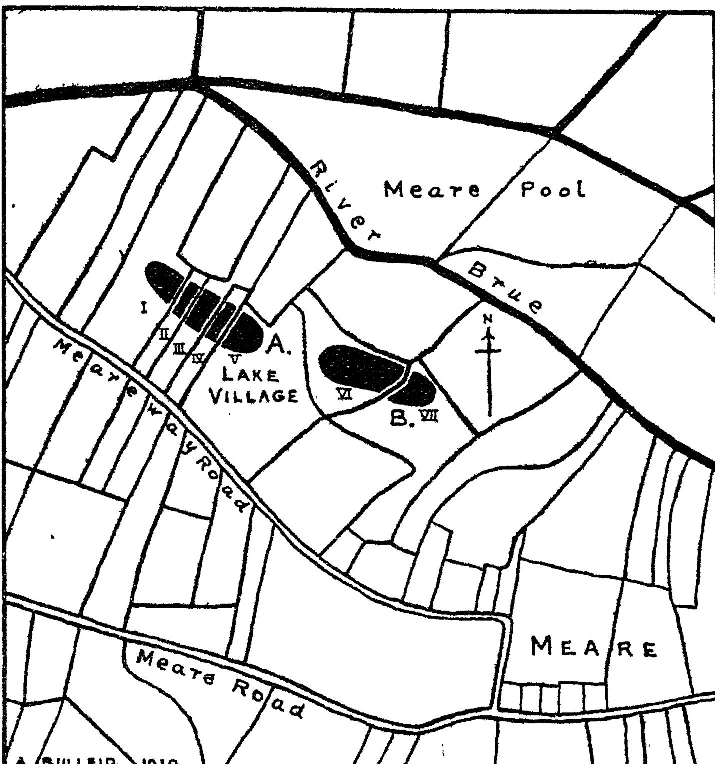
The existence of this site has been known since 1895, but the excavations at Glastonbury being then in progress no systematic examination was attempted until this year. With reference to the situation of Meare, it may be of interest to those who are not acquainted with the locality to give a brief description of it.

The north-central part of Somerset lies between two nearly parallel ranges of hills, the Mendips bordering it along the north-east, with the Quantocks to the south-west. The district so enclosed has a coast-line of some eighteen to twenty miles, and extends inland for the same distance. It is chiefly occupied by low-lying tracts of peat land drained by the Rivers Parret and Brue. Some time during its geological history this locality was a shallow basin-shaped estuary open to the Severn sea. At a later date the southern or inland portion was shut off from the sea by the formation of beds of mud and sand, and con-

[1] The Society's sub-Committee consists of the Rev. E. H. Bates Harbin, Rev. W. T. Reeder, Mr. Charles Tite, Mr. John Morland (Treasurer, Glastonbury), and Messrs. Arthur Bulleid and H. St. George Gray (Joint Secretaries).

verted into a lagoon, which in more recent times was gradually replaced by a series of extensive meres and swamp. In A.D. 1500 five meres still existed, the largest body of water, called 'Meare Pool,' being at that time five miles in circumference.

The Lake Village at Meare lies three miles west of the now fully-explored Glastonbury Lake Village, in the peat moor adjoining the north margin of a low ridge of ground, formerly an island, on which the modern village of Meare now stands, and from 400 to 600 feet south of the River Brue. Before the Brue was embanked, and the



draining of the swamps had been attempted in monastic times, Meare Pool was of far greater extent, and included the Lake Village within the limits of its south-west border. The Lake Village now stands in fertile pasture, the level of the surrounding fields being from 12 to 14 feet above the mean tide level, and is situated 11 miles south-east from the present coast-line at Burnham. The ancient site consists of two distinct groups of low circular mounds A and B, separated by a level piece of ground from 200 to 300 feet in width. So far as a superficial survey permits the two settlements appear to consist of about a hundred dwellings covering parts of seven fields (not five as formerly

stated), and occupying a tract of land that measures roughly from 1,500 to 1,600 feet east and west, by from 200 to 250 feet north and south. The highest mound measures 4·4 feet above the surface of the surrounding field-level. The alluvium covering the adjoining fields varies from 12 to 30 inches in depth. From borings made this year it was ascertained that the depth of peat underlying the dwellings varies from 7 to 11 feet in thickness. Below the peat is a layer of soft grey-coloured clay, lying on beds of lias stone. The recent excavations included the examination of three dwellings, *i.e.*, Mounds I., II., VI., the partial exploration of Mound VII., and the west quarter of Mound V., together with the intervening spaces of level ground situated in Field iv.; also the digging of several trenches on the north and south sides of the marginal mounds in Field iv., with the object of finding the palisading. Although the ground was examined for some 100 feet or more from the dwellings, no border-protection was discovered comparable with that which surrounded the Glastonbury Lake Village.

Mound I.—This dwelling, situated in the S.W. quarter of the village in Field iv., was 32 feet in diameter N.E. and S.W., with an elevation of 1·84 foot at the centre above the surrounding level ground. Its N.W. and W. aspects were incomplete, having been destroyed when the boundary-ditch of the field was cut. It was composed of two floors, the maximum thickness of the clay near the central picket being 2 feet. No wall-posts were discovered. The hearth belonging to floor i. was incomplete when discovered, and 7 inches below the surface; the remaining portion showed that it had been paved with pieces of sandstone. Floor ii. had four superimposed hearths, the uppermost (hearth ii.) being paved with small stones, and the other hearths (iii., iv., and v.) with baked clay.

The substructure consisted of an artificially-placed heap of hard dark peat, resting on the bed of the mere. No timber was observed in the foundation.

Mound II.—This dwelling-mound, situated in the S.W. quarter of the village in Field iv., was 20 feet in diameter N. and S., with an elevation of 0·98 foot at the centre above the level of the surrounding ground. It was joined to Mound I. along the W. margin, and composed of two floors, the maximum thickness of the clay near the central picket being 14 inches. No wall-posts or hearths were discovered. The substructure consisted of a heap of dark-coloured peat, similar to that under Mound I. The greatest number of relics was found below the level of the clay floors, and included quantities of pottery, many fragments being ornamented.

Mound V.—The N. and S. diameter of this mound measured 21 feet, with an elevation of 1·49 foot at the centre above the surrounding field-level. Only a small portion of its W. side was examined, so that a description of its construction and contents cannot be given until it has been fully explored.

Mound VI.—This small mound, situated N.N.E. of Mound I., was 16 feet in diameter N.E. and S.W., with an elevation of 0·8 foot above the surrounding field-level. Its W. quarter was incomplete, having been cut through in making the boundary-ditch of the field. It

was composed of one floor, the maximum thickness of the clay near the central picket being 9 inches. No line of wall-posts or hearths was discovered. The substructure was composed of an artificially-placed layer of dark peat, with no brushwood or timber.

Mound VII. (*in the last Report provisionally called Mound I.*).—This dwelling-mound was of large size, with an elevation of 3·45 feet at the centre, the N. and S. diameter being 32 feet. It was situated in the S.W. quarter of the village in Field iv., and was composed of eight floors with thirteen hearths, twelve of which were superimposed. The total thickness of the clay was 6 feet. The upper part of the mound at the centre was incomplete owing to denudation, and the hearths belonging to the upper floors were consequently missing. The ground under and surrounding the mound was thickly covered with piles, a large proportion of the posts being split pieces of oak. The substructure was 2 feet in depth, and composed of brushwood and timber, on the surface of which planks of oak were placed at intervals. A portion of the N.E. quarter of this mound remains unexplored, and will be completed next season.

The objects found in and around this dwelling were probably more numerous than in any dwelling previously explored, and were of an exceedingly interesting character.

The season's work at Meare Lake Village has been productive of a large number of relics, the quarter of an acre examined throwing a flood of light on the industries and daily pursuits of the inhabitants of this ancient habitation, and revealing more specimens of Late-Celtic art than perhaps the richest quarter of an acre of the neighbouring village at Glastonbury. These remains have afforded evidence that the lake-dwellers of Meare lived under similar physical conditions and civilisation to those of Glastonbury; and although the relics discovered at Meare in 1910 are of the same general type as those found in the other village, several of the objects cannot be matched among the Late-Celtic specimens exhibited in the museum at Glastonbury.

The Meare Lake Village is not what is sometimes styled an 'archæological puzzle,' for its date, or period at any rate, was known from the beginning of the investigations. After a few years' work, however, the date may be even more clearly defined than in the case of the Glastonbury village, which in round numbers may be given as from B.C. 200. Some antiquaries are strongly inclined to narrow these dates, as no development or improvement in the manufactured articles is traceable when comparing objects found on the lowest floors of the dwellings, and in the substructure below, with others from the upper floors, and from just below the alluvial flood-soil which has accumulated since the evacuation of the village. At Glastonbury a few fragments of Roman pottery were found on the *surface* of the mounds but below the flood-soil; as yet nothing attributable to the Romans has been found at Meare.

Numerically the objects of bronze are considerably in excess of those of iron, as was the case at Glastonbury also. Lead from the Mendip Hills is found at Meare in the form of sinkers for fishing-nets, but as yet tin

has not been identified. Bronze was worked on the spot, judging from the remains of four crucibles found, one being an excellent example of the triangular variety with fused bronze still adhering to the inner surface. The perfect articles of bronze include a fibula of La Tène III. type with solid catch-plate, a handsome deep finger-ring of one and a half turns tapering in both directions and ornamented with longitudinal grooves, a heavy snake-ring of plain round wire, a bradawl with shank of square section for insertion into the handle, a broad needle or bodkin, and a harness-ring. In less perfect condition are a pair of tweezers, four other finger-rings, a few broken brooches, pieces of bordering, and other complete and fragmentary objects.

Among the remains of iron is a very large heavy ring, having in one position a moulded ornament in high relief. One or two awls were found, one fixed into its handle of antler, and a gouge used presumably in connection with a brace. The peaceful disposition of the lake-dwellers at Glastonbury was evidenced by the very small number of weapons found. At Meare, however, the ground uncovered has so far produced a tanged spear-head and a javelin-head with corrugated blade, neither of which is socketed.

An amber bead was found in 1908, but glass is revealing itself more plentifully than at Glastonbury. Eight "finds" were made of this material, including a boss or head of a pin, and several beads of considerable interest. The lemon-coloured ring-bead is distinctly of La Tène type; two tiny blue ring-beads were discovered which subsequently led to the finding of eight others near by, in perfect condition. Another of the beads is of iridescent clear glass, ornamented with spirals of opaque yellow glass. A blue bead with three rows of small white rings is very beautiful.

None of the objects of Kimmeridge shale is complete. With the exception of a piece of a shale vessel with cordon, all the fragments are parts of armlets of various diameters and thickness. Most of the specimens bear evidence of the use of the lathe, as indeed some of the pottery does also. Little can be said of the earthenware until the large quantity found has been restored. All sizes of vessels are represented, from a tiny pot about 1¼ inch high to others over 12 inches. The ornamental patterns—curvilinear designs, cross-hatching, dots-and-circles and zigzags predominating—are numerous, and include many which cannot be matched from the neighbouring village; although, on the other hand, many designs typical of the period are repeated. Included among the objects of baked clay are many sling-bullets of the usual form (glands).

Of stone the objects found are also numerous, and comprise a large number of querns, mostly of the 'saddle-shape,' a grindstone, a large circular stone with flat sunk surface having a beaded edge (which may probably have been a mould), various mullers and rubbing-stones, some well-formed flint scrapers and knives, and a polished neolithic celt of igneous stone (probably from Mendip), and probably highly valued as a charm.

Of human remains, portions of three skulls and a molar tooth were found in different places, and the greater part of a thigh bone

(*femur*), bearing evidence not only of having been gnawed and cut, but of having been perforated in two places at one end. In the Late-Celtic camp of Hunsbury a human skull was found having three circular holes bored on the vertex of the head, and arranged as an equilateral triangle.

The most numerous classes of objects found were the worked animal remains—bone, antler, teeth—the latter consisting of perforated canine teeth of dog and boars' tusks. Most of the cut-bone objects are perforated. Worked shoulder-blades of ox and horse are common, one found in 1908 being covered with representations of the dot-and-circle pattern. Their precise purpose remains to be elucidated, and none were found in the Glastonbury village. Bones worked to a point at one end are abundant. The polishing or burnishing bones found consist of the tarsal bones of ox. The knobbed pin and needle are good examples of their kind. A bone tool has been found, used, probably, for ruling double lines in ornamenting pottery. A sickle-shaped knife was formed from a rib bone.

Sawn and polished tines of red-deer antler are common and call for no particular comment; several are perforated. A large antler was found with the burr and points of three tines sawn off, the crown being detached by knife-cutting. One specially well-cut knife-handle of antler has the tang of the iron blade and the rivets still remaining.

The largest dwelling-mound excavated was undoubtedly a weaving establishment, although it is probable, judging from the remains found, that other industries also flourished there. The whorls (used in combination with a wooden spindle for twisting wool or flax into yarn) are among the objects most frequently unearthed, some being in early stages of manufacture; they are formed of stone, bone, or baked clay. Loom-weights of baked clay, mostly of the triangular form for suspension, are also found, and a few bone bobbins.

The large dwelling (Mound VII.) produced no fewer than twenty-one weaving-combs of antler, including eight found in the same mound in 1908. They are not all complete, but on the whole they form a very fine series; the largest measures 8¾ inches long. Many of them bear evidence of very hard wear, being used, no doubt, for pushing home the weft, or woof, through the warp threads. One is probably unique, dentated at both ends and reversible. No dwelling in the neighbouring village produced more than nine of these combs.

The animal remains found this year at Meare are very numerous, and include the bones of small ox (*bos longifrons*), small horse (mostly about the size of the New Forest pony), pig, sheep, red-deer, roe-deer, dog, beaver, and otter. A number of bird bones have been collected which have not yet been identified. Cereals and vegetable products were extremely scarce.

It is hoped that the excavations will be continued from year to year, until an exhaustive examination of the whole area has been completed. The undertaking is already bearing a varied and prolific harvest of archæological material, and revealing remarkable evidence of the life-history and civilisation of the Early Iron Age in Britain.

The Age of Stone Circles.—Report of the Committee, consisting of Dr. C. H. READ *(Chairman),* Mr. H. BALFOUR *(Secretary),* LORD AVEBURY, Professor W. RIDGEWAY, Dr. J. G. GARSON, Dr. A. J. EVANS, Dr. R. MUNRO, Professor BOYD DAWKINS, *and* Mr. A. L. LEWIS, *appointed to conduct Explorations with the Object of ascertaining the Age of Stone Circles. (Drawn up by the Secretary.)*

IT was proposed to continue the excavations at Avebury Stone Circle during 1910, with a view to supplementing the valuable evidence obtained from the excavations of previous years, and for this purpose a grant was applied for and allotted. It was subsequently found impossible to enlist the services of Mr. H. Gray for the conduct of excavations this year, and it was decided that, as it was desirable that the work of continuing the exploration should not be allowed to change hands, the renewal of work on this important site should be postponed until 1911. Mr. Gray is willing to continue the exploration of Avebury Stone Circle under the direction of the Committee, but owing to other engagements of a similar nature he was unable to obtain the necessary additional leave of absence from the Somersetshire Archæological Society, and could not therefore act for the Committee this year. Next year his services will again be available during the spring, and the Committee would urge that the work should then be renewed. It is desirable that as long a time as possible should be assigned to the season's work, since the earthworks are on a very large scale, and the amount of silting which must be moved before the bottom of the fosse can be reached is very great indeed. The Committee ask to be allowed to claim for next year the amount of the grant allotted for 1910, and urge that a further grant of 50*l.* be added to this amount in order that the excavations may be renewed upon an adequate scale.

Archæological and Ethnological Investigations in Sardinia.—Report of the Committee, consisting of Mr. D. G. HOGARTH *(Chairman),* Professor R. C. BOSANQUET *(Secretary),* Drs. T. ASHBY, W. L. H. DUCKWORTH, *and* F. C. SHRUBSALL, *and* Professor J. L. MYRES.

DR. D. MACKENZIE reports: 'This year's campaign in Sardinia was attended by the singular good fortune that had favoured our explorations of former years. Six more dolmen tombs were added to our list of four of last year, making ten monuments altogether of this kind which have been discovered by us. The significance of this discovery may be realised from the fact that, previous to our researches of last year and this, only one monument of this class was known in Sardinia—that near Bironi, referred to by Montelius, and since published by Taramelli. The general scientific result accordingly is: that we can now say definitely not only that the great Tombs

of the Giants were developed from an earlier type of dolmen tomb, as has been conjectured by Montelius and others, but that this development took place on the soil of Sardinia itself. The mysterious civilisation of the dolmen people has long been a puzzle to archæologists. We can now, however, confidently say that in Sardinia at least this dolmen culture represents an early episode in the great Bronze Age civilisation of the Nuraghi.

'A curious circumstance came out in the course of these researches. The dolmens in no case showed that juxtaposition to the Nuraghi which we had previously found to be so constant a concomitant phenomenon in the case of the Tombs of the Giants. One might as well have been in Corsica! And it is well known that in the sister island there are no Nuraghi, and that there the dolmen type of tomb survived throughout the Bronze Age.

'The last part of our campaign was devoted to a partial exploration of the country to westward of Macomer called Planargia as far as Cuglieri and the sea.

'The Nuraghi in this whole region are of the very greatest importance, especially from the point of view of their strategic significance. They form a regular network as far as the sea, and one can see by studying their positions of vantage that they are all directly or indirectly in signalling communication with each other. They are, as Mr. Newton has well remarked, regular block-houses which might very well be compared with those which have performed so prominent a part in modern warfare, as, for example, in the final stages of the Transvaal war.'

The Committee have also received from Dr. Duckworth a summary of a critical study of Sardinian craniology, which the author hopes to publish *in extenso* during the coming year.

Ethnographic Survey of Canada.—Report of the Committee, consisting of Rev. Dr. G. BRYCE (*Chairman*), Mr. E. S. HARTLAND (*Secretary*), Dr. P. H. BRYCE, Mr. C. HILL-TOUT, Dr. B. SULTER, Professor J. L. MYRES, Dr. A. C. HADDON, Dr. F. C. SHRUBSALL, Professor H. MONTGOMERY, Mr. A. F. HUNTER, Dr. J. MACLEAN, *and the* Hon. DAVID LAIRD.

AFTER the appointment of the Committee in Ethnology, the Chairman, being a Councillor of the Archæological Institute of America, attended in December a meeting of the Institute in Baltimore, Maryland. This Institute has a Canadian Section. During the meeting he succeeded in getting a strong resolution passed supporting the action of the British Association in favour of the establishment of a Department of Ethnology at Ottawa.

As President of the Royal Society of Canada, the Convener succeeded in getting further co-operation from the Royal Society as well.

The Chairman being in Ottawa during the meeting of the Dominion

Parliament in March and April called together such members as could be reached, viz.:—

Dr. George Bryce, *Chairman*.

British Association: Dr. Benjamin Sulter, Director Brock, Dr. P. H. Bryce, and Dr. Robert Bell.

Archæological Institute: Principal Peterson and Professor McNaughton, of Montreal; Chief Justice Fitzpatrick, Ottawa; Mr. J. Learmont, Montreal; and Professor Johnson, of Toronto.

Royal Society: Sir Sandford Fleming, Dr. W. D. Le Sueur, and Dr. Benjamin Sulter.

The Committee waited, by appointment, on Sir Wilfrid Laurier and Hon. W. Templeman, Minister of Inland Revenue.

Sir Wilfrid Laurier graciously received the Committee, and after a full interview promised to give favourable consideration to the request. The Chairman watched over the matter further, and co-operated with the Director of the Geological Survey.

It was finally decided to establish a Department of Ethnology under the Geological Survey.

Two sums for the year were added to the Supplementary Estimates of the House of Commons—viz., one of 420*l*. sterling, and the other of 400*l*. sterling, the former to pay the salary of an Ethnologist, the latter for the working of the department. The Geological Department has had already packed away 3,000*l*. sterling worth of most valuable ethnological material, chiefly from British Columbia.

During the coming autumn it is expected that the large National Museum Building in Ottawa, which has been under erection for several years, and is now virtually completed, will be opened, and the Ethnological Department will be installed there and be in operation during the coming winter.

It will be satisfactory to the British Association to know that an appointment has virtually been made of a competent, well-trained ethnologist, who is thoroughly acquainted with American ethnology and archæology, and who will take charge in October. The appointee is a young man and full of zeal.

All Canadians feel grateful for the action of initiative taken in this matter by the British Association at its meeting in Winnipeg.

Notes and Queries in Anthropology.—Report of the Committee, consisting of Dr. C. H. READ (*Chairman*), Professor J. L. MYRES (*Secretary*), Mr. E. N. FALLAIZE, Dr. A. C. HADDON, Mr. T. A. JOYCE, *and* DRS. C. S. MYERS, W. H. R. RIVERS, C. G. SELIGMANN, *and* F. C. SHRUBSALL, *appointed to prepare a New Edition of Notes and Queries in Anthropology.*

THE Committee report that the preparation of the new edition of 'Anthropological Notes and Queries' is nearly completed, and that the volume may be expected to appear in the course of the coming winter. The Committee ask to be reappointed, with the balance in hand.

The Establishment of a System of Measuring Mental Characters.—Report of the Committee consisting of Dr. W. McDougall (*Chairman*), Mr. J. Gray (*Secretary*), Mr. W. Brown, Miss Cooper, Dr. C. W. Kimmins, Dr. C. S. Myers, Dr. W. H. R. Rivers, Dr. W. G. Smith, Dr. C. Spearman, *and* Mr. W. H. Winch.

The object of the work of the Committee during the past year has been to draw up a standard list of mental tests for use in schools and elsewhere. Considerable progress has been made, though the Committee are not yet in a position to publish any of their results, as it is necessary to undertake special researches in order to establish the value and special applicability of some of the tests.

Two meetings of the Committee have been held, and the Chairman has drawn up a memorandum and list of tests which has been sent round to other members of the Committee for suggestions.

As the Committee propose to make observations with the tests in schools, a certain amount of expenditure in printing cards, &c., will be necessary. The Committee therefore ask to be reappointed with a grant of *5l.*

The Ductless Glands.—Report of the Committee, consisting of Professor Schäfer (*Chairman*), Professor Swale Vincent (*Secretary*), Professor A. B. Macallum, Dr. L. E. Shore, *and* Mrs. W. H. Thompson. (*Drawn up by the Secretary.*)

Mrs. Thompson has continued her work on the comparative anatomy and histology of the thyroids and parathyroids and some related structures. The results will be published shortly in the 'Phil. Trans.' of the Royal Society.

The Secretary has been investigating the distribution and microscopic anatomy of the chromaphil tissues in mammals, especially in the dog. The results will be published shortly in the 'Proceedings' of the Royal Society.

Drs. Gardner and Mothersill have been engaged upon a series of experiments devised to ascertain what changes, if any, occur in the chromaphil tissues after extirpation of, or damage to, the adrenal bodies.

Mr. Heddesheimer is studying the distribution and structure of accessory cortical adrenal bodies in mammals.

Dr. Halpenny is continuing his investigations upon the thyroid and parathyroids, and, in conjunction with Mrs. Thompson, has recently published an account of changes in the latter glandules after removal of the thyroid. ('Anat. Anz.')

The Committee ask to be reappointed with a grant of *45l.*

Anæsthetics.—Second Interim Report of the Committee, consisting of Dr. A. D. Waller (*Chairman*), Dr. F. W. Hewitt (*Secretary*), Dr. Blumfeld, Mr. J. A. Gardner, *and* Dr. G. A. Buckmaster, *appointed to acquire further knowledge, Clinical and Experimental, concerning Anæsthetics—especially Chloroform, Ether, and Alcohol—with Special Reference to Deaths by or during Anæsthesia, and their possible Diminution.*

[Plates IV., V., and VI.]

The Committee have held seven laboratory meetings during the past year, at which apparatus for the graduated administration of chloroform and of ether has been examined and discussed, and experiments made therewith upon animals. In addition to such formal experiments in presence of the full Committee, many additional experiments have been made and reported to the Committee:—

1. On the graduated administration of chloroform vapour.
2. On the graduated administration of ether vapour.
3. On the effects upon the course of anæsthesia of diminution and augmentation of the percentage of oxygen in the inspired atmosphere.
4. On the amounts of chloroform present in the blood and in the nervous system of man and of animals after death under chloroform.

These several subjects will be reported upon in due course. They have involved an amount of detailed work that causes the Committee to state that their work could be considerably forwarded if an assistant devoting his whole time to the matter could be engaged.

The Committee, after consideration of several forms of apparatus designed for the graduated administration of chloroform, and after adequate experience of the use of the chloroform-balance for the anæsthesia of animals, believe that this apparatus can be usefully employed in the hospital. They have taken preliminary steps towards bringing the apparatus into a form suitable for this purpose, and they hope that it will shortly be set in operation at St. George's Hospital, under the supervision of Dr. Hewitt.

The principle of this apparatus and its application in the laboratory are described by Dr. Waller in Appendix II. of the Interim Report of the Committee of last year.[1]

The apparatus fulfils what has been recognised by the Committee as the most important indication necessary for safe anæsthesia, viz., the

[1] *Brit. Assoc. Report*, Winnipeg, 1909, p. 303.

uniform, continuous, and regulated administration of chloroform vapour between the limits of 1 and 2 per cent.

The Committee find that the most convenient and reliable method of ascertaining the percentage of chloroform in air consists in directly ascertaining on a balance the difference of weight between two identical counterpoised bulbs, A filled with air, B filled with the mixture to be titrated.

As regards the production of anæsthesia by ether vapour, the Committee are of opinion that the clinical experience obtained with an unknown percentage of ether vapour requires to be complemented by the scientific knowledge of the percentages of ether and air that may be necessary and sufficient. It has initiated experiments upon animals, from which the provisional conclusion is drawn that a mixture composed of approximately one volume of ether vapour and nine volumes of air should be safe and sufficient for the production of surgical anæsthesia.

Comparative experiments have been undertaken for the Committee by Drs. Veley and Waller during the past year on local anæsthetics. The first results have been published in the Proceedings of the Royal Society [1] on the comparative action of stovaine and cocaine as measured by their direct effect upon the contractility of isolated muscle. Further observations have been made by Dr. Veley and Mr. Symes on the effects of stovaine and cocaine, the results of which will, it is hoped, shortly be published.

Dr. Buckmaster and Mr. Gardner have pursued their investigation on 'The Rate of Assumption of Chloroform by the Blood' (Appendix II.), and, arising out of this investigation, have undertaken an elaborate examination into the blood-gases, the results of which will be published in due course.

Drs. Hewitt and Waller (Appendix III.) bring forward definite experimental evidence that the effect of chloroform is aggravated by sub-oxygenation, and attenuated by hyper-oxygenation.

The Committee have co-opted Dr. V. H. Veley as a member, and ask to be reappointed. The work contemplated for the ensuing year comprises:—

1. *On the clinical side:* the practical application to hospital purposes of the chloroform-balance.

2. *On the scientific side:* the further study of the distribution of chloroform in the blood and tissues during life and after death, and of the comparative power of various local anæsthetics.

In conclusion, the Committee think fit to call attention to the fact that the importance of the questions involved is such that during the past year resolutions have been adopted by the General Medical Council and by the Council of the British Medical Association in support of early legislation to secure better regulation of the administration of general anæsthetics, and that the recent report [2] of a Departmental Committee of the Home Office lays special stress upon the need of careful clinical observation controlled by physiological experiments.

[1] B, vol. lxxxii., p. 147, 1909.

[2] Report of Inquiry into the Question of Deaths resulting from the Administration of Anæsthetics. Presented to Parliament by command of his Majesty, March 18, 1910.

APPENDIX I.

On the Principles of Anæsthesia by Ether Vapour.
By Dr. A. D. Waller.

During recent years, in consequence of serious misgivings relating to the safety of chloroform as ordinarily administered, and of the good results of ether reported from the United States, many anæsthetists in this country and on the Continent have been led to adopt anæsthesia by ether, administered by what is termed the open method. 'Open ether' was an expression frequently employed in this connection at the recent discussion on anæsthetics that took place at the last meeting of the British Medical Association, and it is necessary in the first instance to under-
above the face, and brought gradually quite close. But it can also be
'Open ether' implies, I understand, any method by which the patient is not made to breathe and re-breathe the same mixture of air, ether, and accumulating carbon dioxide. It may be effected, as is the Boston practice, by means of a mask saturated with liquid ether, held at a distance above the face, and brought gradually quite close. But it can also be effected by a closed face-piece through which an ether-air mixture of required strength is supplied on the plenum system. In this case the fit of the face-piece is of set purpose incomplete, there being on the plenum system an excess of mixture supplied, which carries away with its overflow the products of expiration. The imperfection of closure can, if preferred, be secured by an actual orifice guarded by an expiration valve.

The factor of primary importance in anæsthesia by ether, as in anæsthesia by chloroform, is quantity—*i.e.*, the percentage of ether in the ether-and-air mixture offered to inspiration. I find as the general result of prolonged trials, conducted in various ways—(1) that the physiological power of chloroform is six to eight times that of ether, or, as I expressed it for the sake of clearness some years ago, that—

$$\frac{\text{Chloroform}}{\text{Ether}} = \frac{7}{1};$$

(2) that whereas chloroform-and-air should be maintained at between 1 and 2 per 100, ether-and-air is required at between 8 and 16 per 100 for the production and maintenance of satisfactory anæsthesia.

Chloroform is *par excellence* the powerful anæsthetic. It is easy to deliver chloroform-and-air continuously at 1 and 2 per 100 *or more*. And by reason of this facility chloroform anæsthesia, unless great care be observed, is dangerous to life.

Ether is *par excellence* the safe anæsthetic. It is comparatively difficult to deliver ether-and-air continuously at 8 to 16 per 100; and by reason of this difficulty ether anæsthesia is more troublesome, the trouble being to give enough ether.

A fortiori it is difficult to give too much ether, while it is only too easy to give too much chloroform.

'Open ether,' in any strict sense of the term, is all but an impossibility with the usual methods of administration by cone or mask,

because, in order to secure an effective percentage of, say, 10 to 15 per cent., the mask must of necessity be almost quite closely applied.

Open ether on the plenum system, by delivery in excess of ether-and-air mixture of known percentage, has not, as far as I know, been applied to the human subject. From my experience of ether upon animals at 8 to 16 per cent., as compared with chloroform at 1 to 2 per cent., I do not think that anæsthesia by ether under the best conditions is preferable to anæsthesia by chloroform under the best conditions.

In the laboratory, where it is possible to employ ether or chloroform under the best conditions, while there is no particular difficulty in the way of anæsthesia by ether, there is also no particular reason for employing ether in preference to chloroform, because the dangers attendant upon the ordinary use of chloroform in hospital and in private practice are not encountered in the laboratory, where the chloroform percentage is regularly under control.

If chloroform were found to be dangerous in the laboratory I should employ ether. And since chloroform is found to be dangerous in the hospital to such a degree that ether, in spite of its drawbacks, is largely employed in its stead, I find it necessary to describe what in my laboratory experience has proved to be the best way of administering ether.

The first principle regulating the administration of ether in the laboratory is the same as it is in the case of chloroform. We require, above all, to know from moment to moment *how much* ether is offered to inspiration. Admitting, as having been ascertained by previous study, that the percentage of ether should be between 8 and 16 per 100 in air, there is no difficulty *in the laboratory* in securing this indication.

The apparatus described in Appendix II. of last year's Report under the name of '*the chloroform-balance*' is converted into an *ether-balance* by two or three simple modifications:—

1. The closed glass bulb which rises and falls with increasing density of the anæsthetic mixture is taken of smaller capacity than for the case of chloroform, by reason of the higher percentages of ether required; 250 c.c. is a convenient size of bulb for an ether-balance.

2. The scale behind the pointer is calibrated for ether instead of for chloroform. The graduation is marked 8, 16, and 24 per cent., to correspond with a chloroform graduation of 1, 2, and 3 per 100. The working zone for ether is between 8 per cent. and 16 per cent., corresponding with the working zone of 1 per cent. and 2 per cent. for chloroform.[1]

[1] *The calibration of an ether-balance.*—Taking (at 0 and 760 mm. Hg) as the

weight of a litre of ether vapour	3·308 grams	
„ „ of air	1·288 „	
the difference is	2·020 „	

so that in a litre flask 1 per cent. of ether vapour, or 10 c.c., is indicated by a weight of 20·20 milligrammes:—

$$1 \text{ milligramme indicates, therefore, } \frac{1}{20{\cdot}2} \text{ per cent.}$$

$$\text{or any percentage P} = \frac{m}{20{\cdot}2} \text{ milligrammes.}$$

3 The flask or bottle containing liquid ether to be vaporised by the current of air should be double, and provided with taps allowing the air to be driven into the balance-case, through either bottle alone or

If, instead of 1,000 c.c., the flask (or bulb) measures v c.c.

$$P = \frac{m}{20{\cdot}2} \times \frac{1000}{v}.$$

If the temperature is T instead of 0° (273 abs.),

$$P = \frac{m}{20{\cdot}2} \times \frac{1000}{v} \times \frac{T}{273}.$$

If the barometer is B instead of 760 mm. Hg,

$$P = \frac{m}{20{\cdot}2} \times \frac{1000}{v} \times \frac{T}{273} \times \frac{760}{B}$$

or

$$\begin{aligned} \log P &= \log m + \log 1000 + \log T + \log 760 \\ &\quad - \log 20{\cdot}2 - \log v - \log 273 - \log B \\ &= \log m + 3 + \log T + 2{\cdot}8808 \\ &\quad - 1{\cdot}3054 - \log v - 2{\cdot}4362 - \log B \end{aligned}$$

or

$$\log P = 2{\cdot}1392 + \log m - \log v + \log T - \log B \quad . \quad . \quad . \quad (1)$$

By means of this formula it is easy, if required, to correct readings for temperature and pressure, or to calculate what volume v must be given to a bulb in order to afford convenient scale readings at average temperature and pressure. Taking these as being 18° and 760 mm., the formula becomes :—

$$\begin{aligned} \log P &= 2{\cdot}1392 + \log m - \log v + \log (273 + 18) - \log 760 \\ &= 1{\cdot}7223 + \log m - \log v \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2) \end{aligned}$$

The application of this simplified formula is best illustrated by examples :—

Question.—What should be the capacity v of a bulb to indicate units per cent. of ether by centigramme increments of weight at normal temperature (18°) and pressure (760 mm. Hg) ?

Answer.—

$$\begin{aligned} \log 1 &= 1{\cdot}7223 + \log 10 - \log v \\ \text{or} \quad \log v &= 2{\cdot}7223 \\ \text{or} \quad v &= 515{\cdot}6 \text{ c.c.} \end{aligned}$$

Question.—What is the weight m indicating 8 per cent. of ether with a bulb of a capacity = 230 c.c. at normal temperature (18°) and pressure (760 mm. Hg) ?

Answer.—

$$\begin{aligned} \log 8 &= 1{\cdot}7223 + \log m - \log 230 \\ 0{\cdot}9031 &= 1{\cdot}7223 + \log m - 2{\cdot}3617 \\ \log m &= 1{\cdot}5425 \\ m &= 34{\cdot}87 \end{aligned}$$

The analogous formulæ for CHLOROFORM—1, for correction of readings; 2, for calculation of v and m at average temperature and pressure—are

$$\log P = 1{\cdot}8377 + \log m - \log v + \log T - \log B \quad . \quad . \quad . \quad (1)$$

and

$$\log P = 1{\cdot}4208 + \log m - \log v \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The litre-weight difference between ether-and-air (2·020) is almost exactly half that between chloroform-and-air (4·045). So that a given bulb graduated for chloroform in units per cent. is graduated for ether in double units per cent., and for all practical purposes the same bulb and balance can be used for ether and for chloroform.

through both bottles in series. The reason for this is the rapid lowering of temperature due to rapid evaporation. For the same reason the bottles are surrounded by a warm water-jacket. In this form the apparatus has proved to be capable of affording a continuous stream of ether-and-air at percentages from 8 to 24 at the rate of 5 to 10 litres per minute—*i.e.*, sufficient for laboratory purposes, and in all probability sufficient for clinical use. The supply of ether vapour at known and controllable percentage is ample for anæsthesia in the laboratory, and sufficient to demonstrate there the fatal effects of overdose by ether in comparison with overdosage by chloroform. In this particular the effect of a 24 per cent. ether mixture is approximately equal to that of a 3 per cent. chloroform mixture. But clinically employed there is little chance of overdosage by ether, of which the characteristic advantage, and drawback, is that it can be used as clumsily as possible with little risk of misadventure other than an imperfect

Units per cent. indicated by a given bulb on a chloroform scale are to be doubled if the bulb is used to indicate ether percentage.

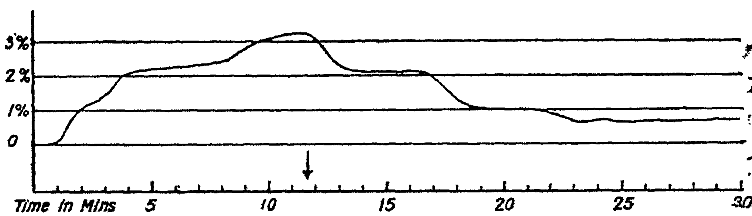


FIG. I.—Graphic record of the chloroform percentage at which anæsthesia was induced. The anæsthesia was complete at the end of 11 minutes at slightly above 3 per cent. The percentage was then reduced in steps to 2 per cent., 1 per cent., and below. Subsequently anæsthesia was maintained at about this percentage for six hours.

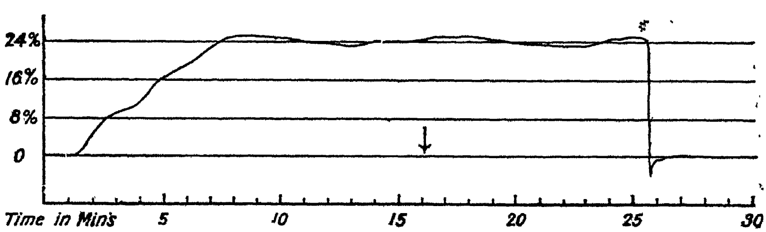


FIG. 2.—Graphic record of the ether percentage at which anæsthesia was produced. The percentage of ether was raised in three steps to 8, 16, and 24 per cent. Anæsthesia was complete at the end of 15 minutes at the point marked ↓. The percentage was maintained at 24 for a further 10 minutes to the point marked * when respiration ceased and the balance-case was opened so that the indicator fell to zero.

The chloroform scale 1, 2, 3 per cent. is at the same time an ether scale 2, 4, 6 per cent. But since we require for ether a scale indicating up to a value of 20 to 25 per cent., it is convenient to use a smaller bulb for ether than for chloroform to obtain indications within such a wide range. Obviously, halving the volume of

anæsthesia. Skilfully employed, as is the practice at the Massachusetts General Hospital, perfect anæsthesia is regularly secured, but by an application of the mask so close and confined that the phrase 'open ether' is no longer properly applicable.

Skilfully employed, as might be the case if the use of the ether-balance were extended from the laboratory to the hospital, it would, I venture to think, be very quickly discovered in the hospital, as it has been in the laboratory, from comparative observations of the use of ether and of chloroform under similar and known conditions, that chloroform under such conditions is as safe as ether and more easily managed.

Therefore, although I am convinced that the 'ether-balance' could be employed in the hospital as effectively as it can be employed in the laboratory, I do not recommend it as a hospital apparatus. Any anæsthetist acquainted with the quantitative principles and use of an ether-balance would necessarily be acquainted with the quantitative principles and use of a chloroform-balance. No one, I imagine, familiar with both instruments could fail to prefer the latter. And my principal reason for describing the ether-balance has been that the description involves considerations that are equally applicable to the chloroform-balance, which, in my opinion, is equally safe and more serviceable.

No instrument for the accurate administration of anæsthetics will ever be devised that can dispense with the exercise of skill and judgment. It requires some little skill to use a balance properly. Judgment and experience are in any case, whether measuring instruments be used or not, the necessary guide as to how much, and at what rate and at what strength, an anæsthetic vapour must be exhibited to different persons under different conditions. By reason of their physical and physiological qualities it has come about that chloroform

the bulb doubles the value of the indications of any given scale, and halving again doubles again. Thus

with a bulb=800 c.c.	the chloroform scale is	1,	2,	3	per cent.
" "	the ether scale is	2,	4,	6	"
with a bulb=400 c.c.	the chloroform scale is	2,	4,	6	"
" "	the ether scale is	4,	8,	12	"
with a bulb=200 c.c.	the chloroform scale is	4,	8,	12	"
" "	the ether scale is	8,	16,	24	"

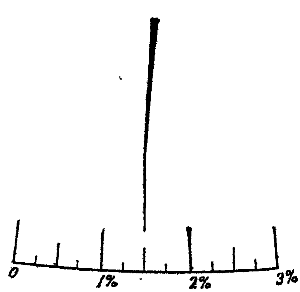


FIG. 3.

is regarded as more dangerous than ether. I have attempted in this report to indicate the precise reason of the difference. And in conclusion, in order to illustrate the point that it is useless to compare drugs without reference to their quantities, I give two records. One, of the first twenty-five minutes of a chloroform anæsthesia in which the percentage was raised for a few minutes up to 3 per cent., then dropped to 2, 1·5, 1, and 0·5 per cent. (and subsequently kept up for six hours at below 1 per cent.); the second, of an ether anæsthesia at 24 per cent., in which respiration ceased at the end of twenty-five minutes.

APPENDIX II.

On the Rate of Assumption of Chloroform by the Blood; and the Percentages of Chloroform found in the Blood of Cats at the Asphyxial Point, using different Strengths of Chloroform-Air Mixture. By Dr. G. A. BUCKMASTER *and* Mr. J. A. GARDNER.

In our last report we brought forward evidence to show that the chloroform content of the blood rises in the initial stages of anæsthesia with great rapidity to a value which approaches a maximum. During this period the quantity of chloroform in the blood appears to affect particularly the respiratory centres, so that breathing becomes slower and often ceases during the first few minutes of anæsthesia, and it may be necessary to resort to artificial respiration in order to prevent the animal dying. The cessation or slowing of respiration at this stage is most liable to occur with high percentages of chloroform—*i.e.*, above 2 per cent. Thus a definite danger-point occurs in the first few minutes of anæsthesia, owing to paralysis of the respiratory nervous mechanism. The steepness of the curve representing the initial rise of chloroform in the blood is also increased by increasing the strength of the chloroform-air mixture inhaled. If the animal naturally passes this stage, and is restored either by stopping the chloroform inhalation or by artificial respiration, then, on continuing the anæsthetic, the amount of chloroform in the blood quickly rises again towards a maximum value. An equilibrium between the pressures which determine the amount of chloroform in the blood subsequently appears to be obtained, the processes of intake and output at the surface of the lung going on side by side. This state of equilibrium is reached and may persist for a considerable length of time. During this period the animal can always be killed by chloroform, even though the percentage of chloroform in the blood rises only very slowly. We would emphasise the point that while the absolute difference between the amounts of chloroform in the blood throughout this anæsthetic stage and that present at death is very small—*e.g.*, 20 mg. per 100 compared with 45 mg. per 100—the relative difference is considerable—*i.e.*, more than double.

Further evidence on these points is given by the experiments recorded in the following tables:—

Rate of Assumption of Chloroform by the Blood. Prior Anæsthetic N_2O—$CHCl_3$, Administered from Bags and Tested by Densimetry.

Experiment 1.—$CHCl_3$ 2 per cent., from bag:—

Time in min.	$CHCl_3$ per cent. of blood	
0	·0198	
10	·0266	
20	·0300	
30		
40	·0400	
50	·0430	asphyxia.

Experiment 2.—$CHCl_3$, from bag as before:—

2	·0056	
3	·0078	
6	·0157	
11	·0193	
16	·0300	
30	·0250	
40	·0325	
50	·0460	
60	·0290	
70	·0430	
80	·0510	asphyxia.

Experiment 3.—$CHCl_3$ 2 per cent., from special Woulff bottle at constant temperature, and frequently tested by densimetry:—

1	·0130	resp. 180
3	·0247	resp. 91
6	·0236	resp. 77
10	·0340	
15	·0220	
20	·0310	
30	·0320	
40	·0460	
50	·0380	
81	·0470	
93	·0510	asphyxia.

Experiment 4.—$CHCl_3$, given by bottle as before, and frequently tested; 3–4 per cent. all the time:—

1	·0498	
3	·0660	animal stopped breathing, then slow breathing, and recovered itself without cessation of $CHCl_3$.
6	·0366	
10	·0378	
15	·0520	
20	·0600	breathing regular and steady.
30	·0620	
40	·0610	
50	·0650	
55	·0660	
58	·0650	asphyxia.

Experiment 5.—In which successively increasing amounts of $CHCl_3$ were given from tested bags :—

$CHCl_3$ 2 per cent.	4	·0157	
3 ,,	15	·0220	
3 ,,	15½	·0370	
	23		
4·5 ,,	23½		
	32	·0399	
	46	·0520	asphyxia.
		.0610	animal allowed to recover partially, then killed by air bubbled through $CHCl_3$.

Experiment 6.—Instance of a troublesome animal that kept ceasing to breathe and had abnormal and varying type of respirations and unusual twitchings :—

		Time in min.	$CHCl_3$ per cent. of blood.	
$CHCl_3$	2 per cent.	7	·0120	
		26	·0220	
bags changed to	3 ,,	41	·0310	(near asphyxial point).
			·0280	animal brought round artificially and killed by 4·5 per cent. in 11 minutes.

Series of Data as to the Amount of Chloroform in the Blood at the Asphyxial Point under Various Percentages of Chloroform Inspired.

1. Experiments in which asphyxia was rapidly reached—within fifteen minutes, and before any equilibrium had been reached. 'Early asphyxia':—

Average of number of experiments	Inspired air, chloroform per cent.	Mgms. of per 100 gms. of blood	Limits in extreme experiments
7	3–4	48	25–63
3	4–5	38	37–41
2	5	40	40–41

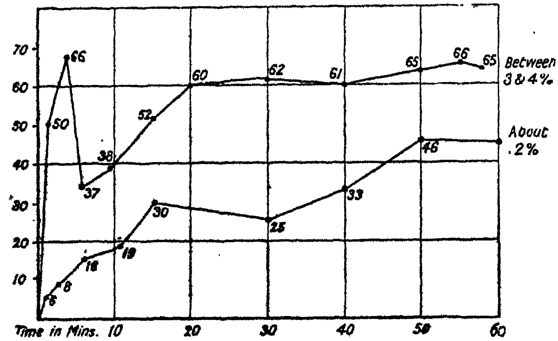
2. Experiments in which asphyxia occurred after equilibrium had been established. 'Late asphyxia':—

15	about 2	45	35–55
7	3	52	42–61
5	3·5	49	48–57
3	4	53	44–68
2	4–5	59	41–77

From the data given, which obviously are as yet insufficient to warrant a precise conclusion, it is clear that the differences in experiments as regards the chloroform percentage in inspired air are so great that it is difficult to assign a value to the relation. Nevertheless, there is on the whole at the asphyxial point an augmented percentage of chloroform in blood with augmented percentage in inspired air.

Without laying undue stress upon the results of individual experiments, we may give the following diagram to illustrate the actual percentages found in the blood of two different animals anæsthetised by chloroform at between 3 and 4 per cent. and at about 2 per cent.

FIG. 4



Plotted curve of the amount of chloroform found in the blood of two cats during the first hour of administration of chloroform at between 3 and 4 per 100 and at about 2 per cent. respectively as determined by densimetry.

APPENDIX III.

The Influence of Oxygen upon the Anæsthetic Effect of Chloroform. By F. W. HEWITT, *M.A., M.D., and* A. D. WALLER, *M.D., F.R.S.*

The ill-effects of chloroform sometimes encountered in practice, referable to a state of sub-oxygenation, and the considerable measure of success that the Roth-Dräger apparatus[1] has met with in Germany, as well as the definite evidence of the beneficial effect of oxygen inhalation that has been brought forward by Leonard Hill, have induced us to make careful experiments under strict laboratory conditions as to the comparative effects of chloroform with deficiency and with excess of oxygen in the diluent air.

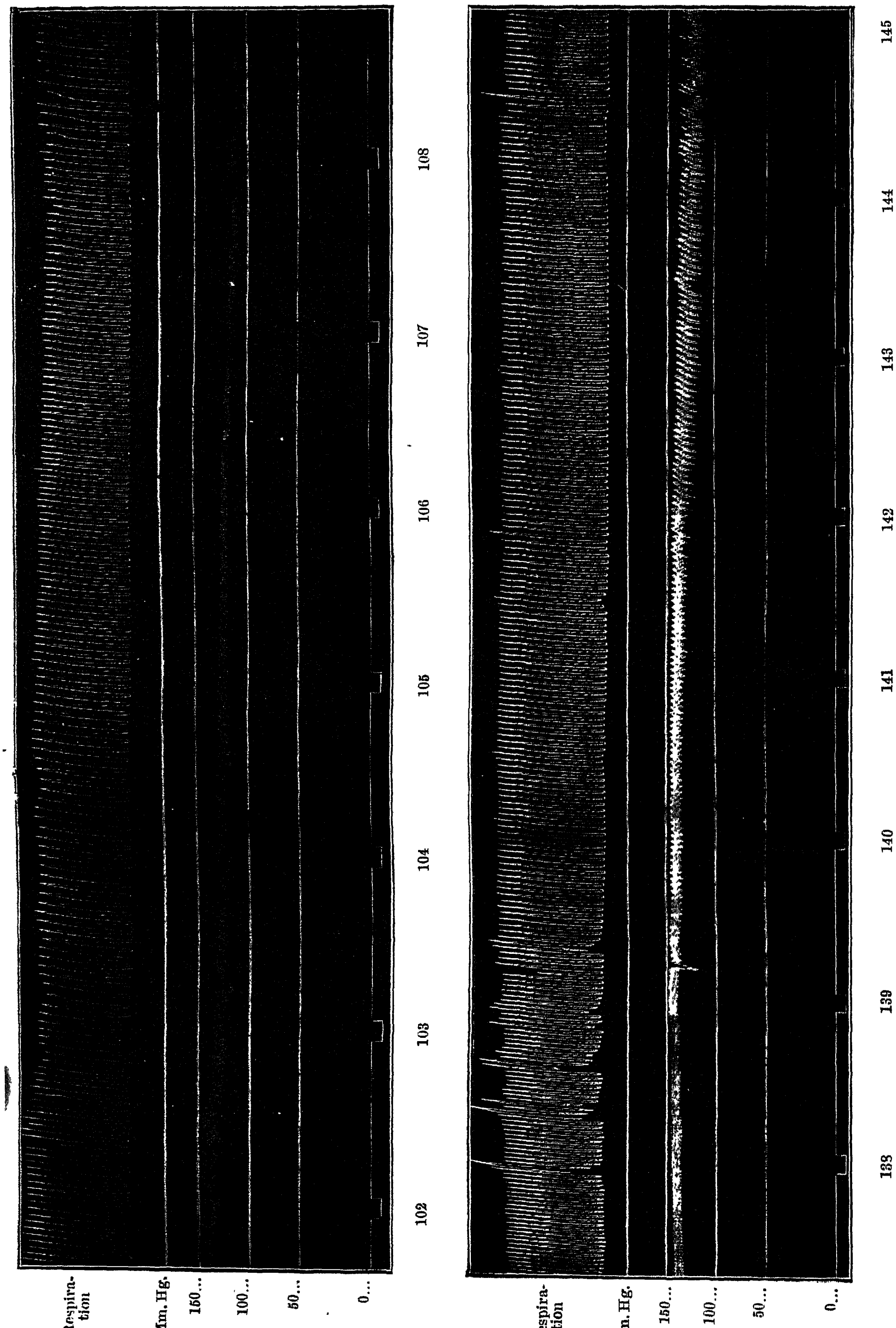
The first condition necessary—*i.e.*, an unlimited supply of chloroform vapour of definitely known constant percentage, whether in air or in air *plus* or *minus* a given proportion of oxygen—is fulfilled by the chloroform balance far more effectively and conveniently than is possible in any other manner. The slight correction of graduation rendered necessary by the fact that the density of mixture is slightly altered by the variation of oxygen is easily corrected by means of a light rider on the counterpoise side of the beam.

This automatic correction of zero requires no calculation, and the correction within the scale itself is practically negligible. With the three mixtures we have employed—viz., oxygen 7 per cent., 21 per cent., and 97 per cent.—the weight-differences at the two extremes do not exceed ½ per 1,000 and 1 per 100 respectively.

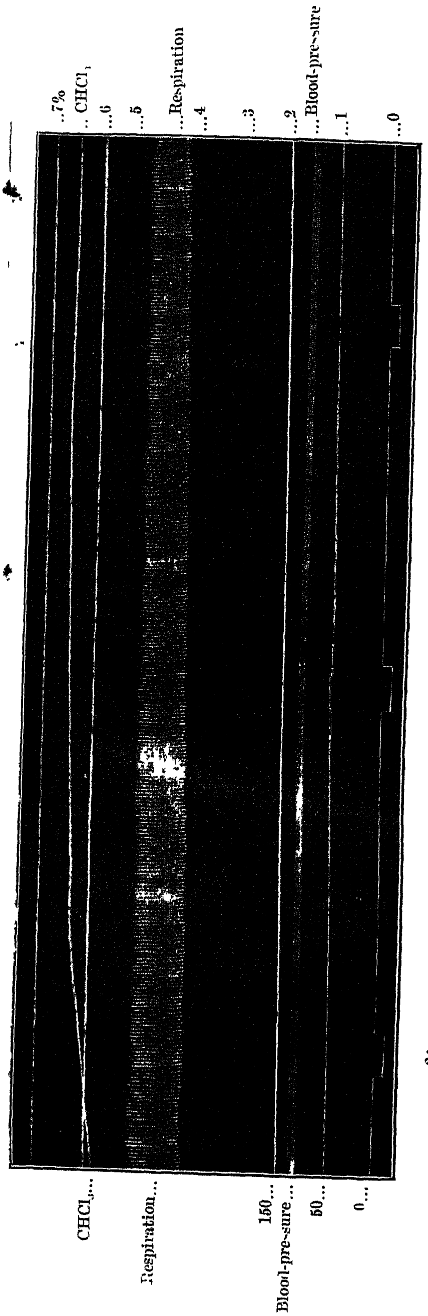
The great advantage of possessing this guarantee of the constancy of chloroform percentage during prolonged experiments, as compared with the insecurity offered by any fixed instrumental graduation, or even by limited volumes of mixture occasionally sampled more or less accurately

[1] The delivery of this apparatus was examined and reported on, six years ago, by Dr. Waller. *British Medical Journal*, December 24, 1904, p. 1687.

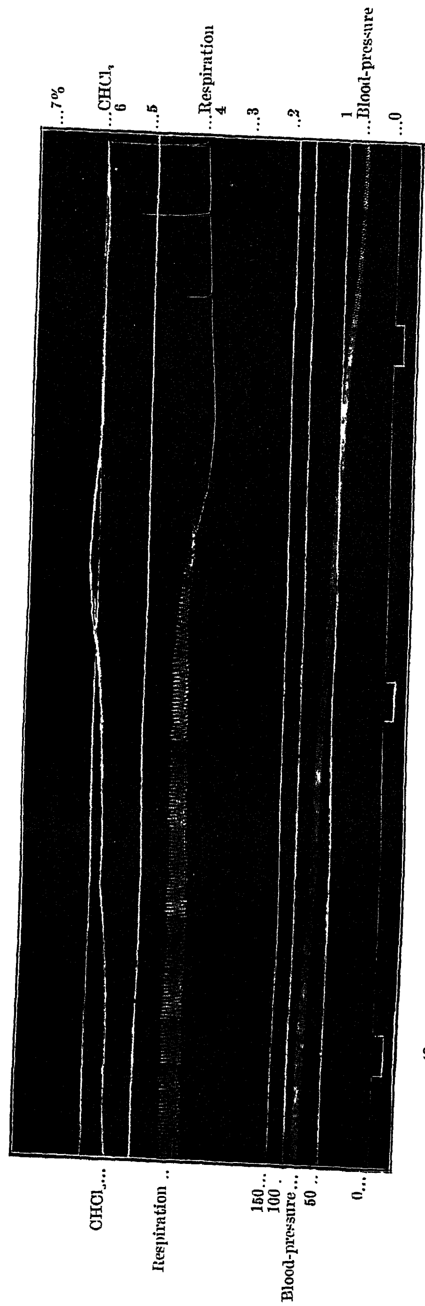
Illustrating the Report on Anæsthetics.



Illustrating the Report on Anæsthetics.



Effect on respiration and blood-pressure of chloroform of percentage reaching to 6·5 per cent., with the percentage of oxygen at about 95 per cent.



Effect on respiration and blood-pressure of chloroform of percentage reaching to 6 per cent. with air, *i.e.*, with oxygen at about 20 per cent.

Illustrating the Report on Anæsthetics.

by a laborious chemical analysis, consists in the feeling of certainty that irregularities of results, if present, are not due to instrumental irregularities of quantity, but are in reality the expression of physiological differences. As a matter of fact, however, under these conditions, where there is no irregularity of chloroform percentage, there is a remarkable regularity of physiological effects.

A comparatively small number of experiments in which the chloroform percentage has been maintained scrupulously constant at, say, 2 per cent., while the oxygen percentage has been taken at and below and above the normal—*e.g.*, at 7 per cent., at 21 per cent., and at 97 per cent.[1]—enables us therefore to conclude with certainty that the intensity of the chloroform effect is greater than normal at a lower percentage of oxygen, less than normal at a higher percentage of oxygen. The following experiments and records are given as being representative :—

Experiment 1, *April* 29.—To demonstrate the effect of excess and deficiency of oxygen upon anæsthesia by chloroform vapour at 2 per cent.

Cat, 3·2 kilos., anæsthetised under a bell-jar by ether at an unknown (high) percentage, subsequently maintained in anæsthesia of variable depth by inhalations of chloroform at 2 per cent. as indicated in the protocol. Each period of anæsthesia lasted for five minutes. The depth of anæsthesia was gauged by the corneal reflex, which was more or less brisk at the outset of each period, and more or less completely abolished at the end of the period. When necessary the anæsthesia was maintained by a sufficient amount of ether vapour.

Time. 0 min. 14 „	Anæsthesia by ether. Tracheotomy under ether cannula in carotid		Blood pressure	Respiration	Corneal reflex at the end of each period of $CHCl_3$
	%	%			
55 to 60	$CHCl_3$ 2,	Oxygen 95	Fall from 150 to 100 mm. Hg	No diminution	Diminished
(Fig. 5) 67 to 72	2	20	„ 150 to 75 „	Diminution	„
(Fig. 6) 80 to 85	2	7	„ 130 to 60 „	Arrest	Abolished
(Fig. 7) 102 to 107	2	95	„ 140 to 120 „	Slight diminution	Diminished
123 to 128	2	7	„ 140 to 50 „	Arrest	Abolished
136 to 141	0	7	„ unaltered „	Unaltered	Unaltered
(Fig. 8) 148 to 158	2	7	„ 130 to 40 „	Arrest	Abolished
165 to 180	2	20	„ 125 to 100 „ (where it remained for 15 min.)	Diminished	„
180 to 182	5	20	Fall from 100 to 25 mm. Hg	Arrest and death	

It is clear from this protocol that the effect of chloroform is regularly greater and smaller with smaller and greater percentage of oxygen, as gauged by the fall of blood pressure, the reduction of respiration, and the abolition of the corneal reflex. From which it appears to be legitimate to infer that under such conditions oxygen has an influence antagonistic to that of chloroform. This counteraction appears to hold good for the higher and more dangerous percentages of chloroform, as indicated by the next experiment.

[1] Brin's cylinders of oxygen, according to Mr. Gardner, have 97 per cent. of oxygen and 3 per cent. of nitrogen. With 2 per cent. of chloroform the oxygen percentage when Brin's oxygen is employed is approximately 95 per cent.

Experiment 2, *June* 3.—To demonstrate that it is easier to kill by chloroform-and-air than by chloroform-and-oxygen. Cat, 2·2 kilos., anæsthesia in bell-jar by $CHCl_3$, 2 per cent. at 4·51. Cannulæ in trachea and carotid at 5·14. Anæsthetic mixtures of (1) chloroform-and-oxygen, (2) chloroform-and-air inspired by animal from balance-case through a Chauveau's cannula.

	Time				Blood pressure
	5·16 (25th min.)	$CHCl_3$	3% + Oxygen 95 %		125 mm. Hg.
	5·20 (29th ,,)	,,	3%	Corneal reflex abolished	125 ,,
	5·21 (30th ,,)	,,	4%		125 ,,
	5·22 (31st ,,)	,,	4%		120 ,,
	5·23 (32nd ,,)	,,	5%		100 ,,
	5·24 (33rd ,,)	,,	6%		90 ,,
Fig. 9	5·25 (34th ,,)	,,	6%	Respiration diminished	80 ,,
Fig. 9	5·26 (35th ,,)	,,	6%		80 ,,
Fig. 9	5·27 (36th ,,)	,,	6·5%		80 ,,
	5·28 (37th ,,)	,,	6·5%		80 ,,
	5·29 (38th ,,)	,,	6·5%		80 ,,
	5·30 (39th ,,)	Chloroform off until corneal reflex was just perceptible			80 ,,
	5·31 (40th ,,)	$CHCl_3$	—	(Recovery)	85 ,,
	5·32 (41st ,,)	,,	—		100 ,,
	5·33 (42nd ,,)	,,	—		130 ,,
	5·34 (43rd ,,)	Chloroform on (with air), *i.e.*, oxygen 20 %			140 ,,
	5·35 (44th ,,)	$CHCl_3$	4%		140 ,,
	5·36 (45th ,,)	,,	5%		110 ,,
	5·37 (46th ,,)	,,	5%		90 ,,
	5·38 (47th ,,)	,,	5·5%		85 ,,
Fig. 10	5·39 (48th ,,)	,,	5·5%		75 ,,
Fig. 10	5·40 (49th ,,)	,,	6%	Respiration ceases	60 ,,
Fig. 10	5·41 (50th ,,)	,,	6%		40 ,,
	5·42 (51st ,,)	,,	6%	(Death)	30 ,,

The Dissociation of Oxy-Hæmoglobin at High Altitudes.—Report of the Committee, consisting of Professor E. H. STARLING (*Chairman*), Mr. J. BARCROFT (*Secretary*), *and* Dr. W. B. HARDY.

THE Committee appointed in 1909 were prepared to place the grant at the disposal of the Secretary for the purpose of carrying out the investigations in any suitable place; they expressed a preference, however, in favour of the laboratory at Monte Rosa. It was found impossible for the Secretary to carry out his intention of going there in the summer of 1910, and therefore the grant has not been drawn.

The Committee think it extremely desirable that the work should be undertaken, but they realise that the progress which one person can make with such a research in a few weeks, under the difficulties which must necessarily be encountered, is very small. They have therefore

ascertained that Mr. Ff. Roberts is prepared to take part in the work, should the funds necessary to meet his out-of-pocket expenses be forthcoming. Mr. Roberts is acquainted with the technique required for the research.

The Committee therefore request that the grant of last year be held at their disposal, and that in addition a like sum be added to it.

Electromotive Phenomena in Plants.—Report of the Committee, consisting of Dr. A. D. WALLER (*Chairman*), Mrs. WALLER (*Secretary*), Professors F. GOTCH, J. B. FARMER, *and* VELEY, *and* Dr. F. O'B. ELLISON. (*Drawn up by* Dr. A. D. WALLER.)

I. *Introduction.*

IN last year's report of the Committee upon the Electrical Phenomena and Metabolism of *Arum Spadices* principal stress was laid upon the effects of heat upon the excitatory phenomena of animal and vegetable tissues, gauged principally by their electromotive responses.

We showed then (1) upon muscle, (2) upon nerve, (3) upon petioles of plants that the brief application of an amount of heat insufficient to effect injury elicits an electrical change that is the reverse of that elicited by injury and by excitation; and as general conclusion of our observation we found that the effect of 'thermic stimuli,' so called, is anti-excitatory or inhibitory in character.

Without having fully reconciled the apparent incongruity of this result with the well-known fact that rise of temperature accelerates chemical change and increases the excitability of living tissues in relation to brief stimuli, we have pursued our investigation of the general relations between physiological phenomena and temperature in both animal and vegetable tissues.

We have in particular investigated (1) the rate of action of drugs upon muscle and (2) the rate of change taking place in laurel leaves. The study of laurel leaves has brought us back to the consideration of the electrical phenomena associated with enzyme effects, and has led us on to a special study of hydrocyanic acid. The elaboration of a method for the quantitative estimation of hydrocyanic acid in laurel leaves has placed in our hands a method for its quantitative estimation in minute quantities in animal as well as in vegetable tissues. We have further satisfied ourselves that the method is applicable (1) to medico-legal cases of suspected poisoning by prussic acid or by cyanides, and (2) for the purposes of agricultural chemistry.

Communications relating to the subject-matter dealt with by the Committee have been made during the past year to the Physiological Society and to the Royal Society. As regards the medico-legal application of the method, we intend to submit it to criticism in the proper quarter by a communication to the Royal Society of Medicine.

II. *Rate of Intoxication and Temperature.*

In order to investigate the influence of temperature upon the rate of intoxication we took observations on the rate of action upon muscle at temperatures between 7° and 25° of alcohol, chloroform, quinine, and aconitine.

With a normal (5·8 per cent.) solution of ethyl alcohol, *e.g.*, we found that muscular contractility was abolished at 24° in six minutes, at 17° in ten, 14° in twelve, 12° in fourteen, and 7° in twenty. These data can be dealt with (*a*) geometrically by plotting their values on squared paper, and (*b*) mathematically by applying a modification of Esson's formula.[1]

(*a*) Plotting times along the abscissa and temperatures along the ordinate the curve of the relation is evidently very nearly geometric; the toxic effect takes longer and proceeds more slowly at low than at high temperature.

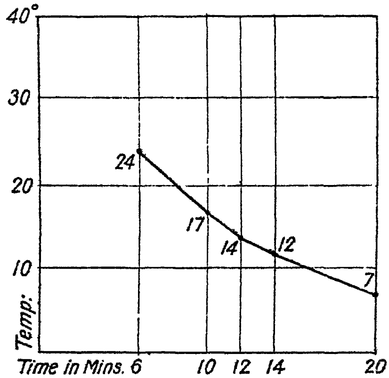


FIG. 1.—Curve expressing the relation between the times taken by the complete intoxication of a muscle by ethyl alcohol, and the temperatures between 24° and 7°, at which the intoxication was effected.

(*b*) The modification for our purpose of Esson's formula is as follows:—

$$\frac{\log L_0 - \log L_1}{\log T_1 - \log T_0} = m,$$

where L_0 and L_1 are the lengths of time between the application of the drug and the cessation of contraction; T_0 and T_1 the absolute temperatures at which the intoxication took place; m the experimental constant. (The value of m obtained from this formula is 1/555 of the value μ calculated by Arrhenius' formula.)

The values of m came out as follows:—

	m	Temp. coeff. for 10°
For alcohol	20·5	2·02
„ chloroform	14·3	1·63
„ quinine	26·6	2·52
(Hydrogen peroxide and hydrogen iodide)	20·38	—
(Chloric acid and ferrous sulphate)	26·5	—

[1] Veley and Waller, 'Observations on the Rate of Action of Drugs upon Muscle as a Function of Temperature,' *Proc. Roy. Soc.*, B, vol. lxxxii., p. 205, 1910.

III. *An Objection met.*

An objection having been raised[1] to the effect that the direct action of a poison upon muscle was not necessarily of a 'physiological' order, but that it was of the same character as the arrest of action of unorganised ferments, the action of aconitine upon (1) ptyaline and (2) invertase was compared with its action on muscle. Aconitine, which promptly abolished muscular contractility when used in $n/10,000$ solution, did not inhibit the action of these ferments in $n/1,000$ and $n/100$ solution.[2] The difference shows that the action of a poison upon protoplasm must not be classified with the action of a poison upon an enzyme.

IV. *The Evolution of Hydrocyanic Acid by Laurel Leaves* (Prunus laurocerasus).

The evolution of hydrocyanic acid by laurel leaves in consequence of congelation or of their exposure to the action of anæsthetic vapours (first pointed out by Raphael Dubois and more recently studied by Guignard and by Armstrong) affords a case where it is easy to study simultaneously (*a*) the product of an enzyme, and (*b*) the alterations of electrical response that take place under the influence of anæsthetics. In this case, in consequence of the action of, *e.g.*, chloroform, an enzyme or enzymes of the emulsin type effect the hydrolysis of a glucoside (prulaurasin), and hydrocyanic acid is produced, the presence of which is readily detected by means of picrate of soda test-papers (Guignard).

Our first observations were directed to a determination of the parallelism or the want of parallelism between the chemical and the electrical change, regarding these two changes as the associated consequence of the same excitatory disturbance of protoplasm by the agency of the anæsthetic poison. But further observations in which a method for the quantitative estimation of hydrocyanic acid was elaborated indicated the insufficiency of any such simple point of view. The progressive evolution of HCN by anæsthetised leaves immersed in picrate of soda, correlated with the progressive diminution of their electrical response, shows that the HCN begins to appear as the electrical response disappears, and that it continues to be evolved as a post-mortem enzyme product long after all electrical sign of life has been abolished. The electrical response is abolished in a few minutes, and the abolition is final. The evolution of HCN commences to be manifested in a few minutes and continues actively for many hours or days.[3] The relation between blaze currents and the evolution of HCN is dealt with in the Appendix by Mrs. A. M. Waller.

V. *Protoplasm and Water.*

The inference to be drawn from this is that the hydrolysis of which hydrocyanic acid is the consequence is a sign of death rather than a

[1] *Proc. Physiol. Soc.*, February 16, 1910.
[2] Bywaters and Waller, *Proc. Physiol. Soc.*, June 18, 1910.
[3] A. D. Waller, 'Anæsthetics and Laurel Leaves,' *Proc. Physiol. Soc.*, June 18, 1910.

sign of life. Without denying as a possibility that the change may take place in slight degree during life, we recognise as the major fact that it does take place when, as shown by the electrical response, the living state has come to an end, and we therefore regard the entire phenomenon not as a manifestation of excitation or intensification of the living state, but as a liberation supervening upon a depression or suppression of the living state.

The alterations of weight that take place in anæsthetised or otherwise poisoned leaves to which attention was drawn at a recent meeting of the Royal Society by H. E. and E. F. Armstrong are quite intelligible from this point of view. A normal leaf, in water and in dry air,

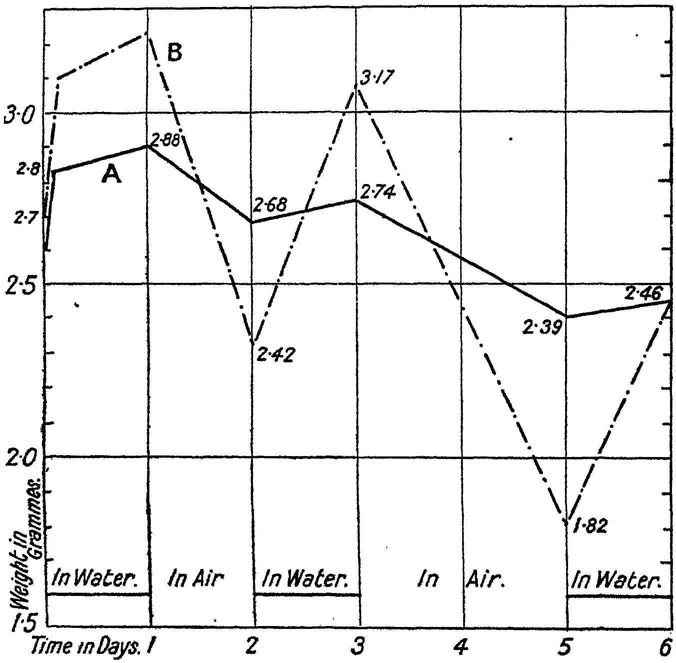


FIG. 2.—Described in the text.

gains and loses in weight very little in comparison with the gain or loss of an anæsthetised leaf, because in the former the association of water with protoplasm is comparatively firm, whereas in the latter water is more easily absorbed and lost. Figuratively expressed, the dead matter of a chloroformed leaf is more obedient to variations of its surrounding water than is the living matter of a normal leaf. This point is illustrated in fig. 2, giving the weights of two similar leaves, one of which, A, was normal, while the other, B, had been chloroformed, both leaves being subsequently immersed in water and exposed to the air as indicated in the figure. The fluctuations of weight by gain and loss of water were much greater in the chloroformed leaf B than in the normal leaf, A.

VI. *A New Method for the Quantitative Estimation of Hydrocyanic Acid.*

The most important progress made during the past year has consisted in the elaboration of the method for the quantitative estimation of small amounts of HCN—*i.e.*, less than 1 milligramme.[1] A colorimetric method has been worked out by means of which it has been found possible to estimate in thousandths of a milligramme the evolution of HCN by a single laurel leaf during short periods of time—by the day

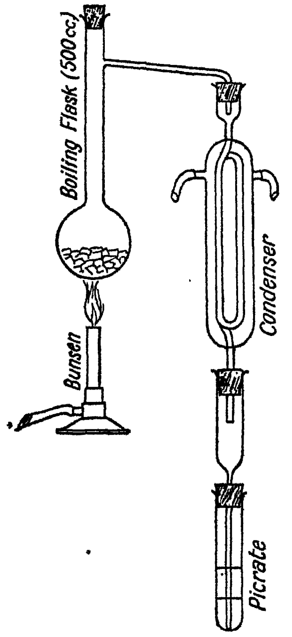


Fig. 3.—Apparatus for the distillation and subsequent estimation of minute quantities of HCN in a vegetable or animal tissue.

or hour at ordinary temperatures, by the minute at a temperature of 40°. Fig. 3 gives a curve of HCN evolution taken at 40° in periods of five minutes. Fig. 4 of the same, taken on two individual leaves at one minute periods, with the specific purpose of determining as nearly as might be the time lost between the moment of immersion and the first appearance of HCN. In the two cases examined this first appearance took place during the fourth and during the fifth minute of anæsthesia. Under similar conditions the electrical response disappeared during the third and fourth minute.

The procedure consists in matching with a colour scale containing known amounts of hydrocyanic acid in picrate of soda the colour of

[1] Waller, 'A New Method for the Quantitative Estimation of Hydrocyanic Acid in Vegetable and Animal Tissues,' *Proc. Physiol. Soc.*, June 18, 1910; *Proc. Royal Soc.*, June 20. 1910.

picrate of soda into which hydrocyanic acid has diffused or has been distilled (fig. 5).

The colour of the compound produced by the reaction (sodium is *iso*-purpurate) is remarkably stable. It is not changed by prolonged exposure to direct sunlight, nor by boiling. Its intensity is such that a convenient unit is afforded by one milligramme HCN per litre of dilute picrate (picrate acid 0·1; sodium carbonate 1; water 100).

For practical use it is convenient to prepare two scales:—

T 1 to T 10	containing	1 to 10	milligrammes HCN per litre
T 0·1 to T 1	„	0·1 to 1	„ „ „

The coarser of these two scales is intended for use in ordinary 2-ounce bottles with 50 c.c. of liquid; the finer for use in flat-bottomed tubes of the Nessler type with 20 c.c. of liquid.

In either case the actual estimation consists in the determination of a colour number, T, which indicates millionths of a gramme HCN per 1 c.c., and gives therefore by simple multiplication by the number of c.c. the absolute amount of HCN present in any given volume—*e.g.*, a tint

T 1 in 100 c.c.	= 0·000100	grm. HCN
T 3 in 50 c.c.	= 0·000150	„
T 0·5 in 20 c.c.	= 0·000010	„

There is no danger of confusing HCN with either sugar or creatinin, since neither of these substances are volatile. In the case of animal tissues, acetone, if present, produces only a very slight discoloration, and is readily recognised by the iodoform test.

Illustrative Experiments.

The application of the method as regards laurel leaves will be most clearly appreciated by inspection of figs. 4 and 5. As regards animal tissues, it will be sufficient to quote four experiments from among many others.

Exp. 12.—Cat, 2 kilos. Death by injection of 0·005 grm. KCN (=·002 grm. CN). Distillates of 10 grm. into 10 c.c. picrate.

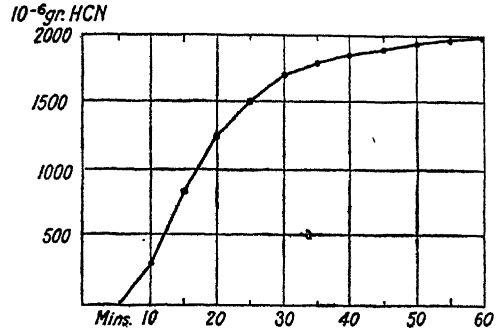
Distillate	1. Blood	T 2·5×21 c.c.	52 (10^{-6} grm. HCN)
„	2. Brain (8 gr.)	T 4·5×20×10/8	112 „
„	3. Heart	T 1·3×20	26 „
„	4. Muscle	T 0 ×20	0 „

Exp. 13 (control).—Cat, 2·5 kilos. Death by chloroform at 5 per cent. Distillates as in Exp. 12 of blood, brain, heart, and muscle gave no discoloration, *i.e.* no sign of HCN.

Observation 24.—Man, aged sixty, found dead in bed on the morning of June 21. Distillates taken on June 23 of 10 grm. of tissue into 10 c.c. of picrate to a volume of 20 c.c.

Distillate	1. Blood	T 2	40 (10^{-6} grm. HCN)
„	2. Brain	T 1	20 „
„	3. Heart	T 2	40 „
„	4. Muscle	T 0·5	10 „
„	5. Viscera (and contents)	T 20	400 „

Observation 25 (control).—Woman, aged fifty. Death under chloroform. Distillates as in Observation 24 of blood, brain, heart, muscle, and viscera gave no marked discoloration,[1] *i.e.*, no sign of HCN.



0– 5 min.	000	10^{-6}gr. HCN
5–10 „	+300	
10–15 „	+550	
15–20 „	+400	
20–25 „	+240	
25–30 „	+200	
30–35 „	+100	
35–40 „	+ 75	
40–45 „	+ 50	
45–50 „	+ 40	
50–55 „	+ 25	
55–60 „	+ 20	
0–60	2000	

FIG. 4.—Evolution of hydrocyanic acid by a laurel leaf weighing 1·1 grm. in chloroform picrate at 40°; picrate changed every five minutes. The total amount of HCN evolved was two milligrammes.

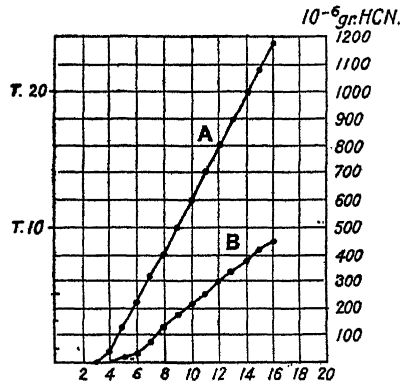


FIG. 5.—Evolution of HCN by two laurel leaves A and B, weighing 0·9 and 1·2 grm., immersed in chloroform picrate at 40°; picrate changed every minute. In both cases the portion of curve observed is approximately a straight line rising at a rate of 100 millionths per minute in A, and of 40 in B. In A the first appearance of HCN took place in the fourth minute, in B in the fifth minute.

VII. *Summary and Conclusion.*

1. In consequence of the action of chloroform on the leaves of *Prunus laurocerasus*, the electrical response is abolished within a period of five minutes. The leaves are then dead.

2. Coincidently with the abolition of the electrical response an evolution of hydrocyanic acid commences. The evolution continues for many hours after death of the leaf.

[1] A faint discoloration, appreciable only by the finer scale, of an approximate value T 0·2, is obtained with normal tissues. It is probably due to the presence of acetone, as shown by Lieben's iodoform test.

3. The rate of intoxication of a muscle by an anæsthetic is a function of the temperature at which the intoxication takes place.

4. The rate of evolution of hydrocyanic acid by a laurel leaf is a function of the temperature at which it takes place.

5. A method has been elaborated by which it is possible to measure the output of HCN by a laurel leaf during a period of one minute. The output has been found to be, *e.g.*, 0·1 milligramme per gramme per minute at 40° and 0·01 at 20°.

6. The method is applicable quantitatively as well as qualitatively to any vegetable and animal tissue.

7. By means of this method the distribution of a cyanide in the body of a poisoned animal and of man can be conveniently determined.

8. The organs in which a poisonous cyanide is found *post-mortem* in greatest relative amount are the heart and the brain. It is found in smallest relative amount in skeletal muscle.

APPENDIX.

On the Blaze Currents of Laurel Leaves in relation to their Evolution of Prussic Acid. By Mrs. A. M. WALLER.

The presence of a 'blaze current '[1] is a sign that the plant or animal tissue is living and also how much it is alive (Waller). A young laurel leaf kept in a moist tube from May 26 to June 9, and tested occasionally, continued to give the blaze current quite normally. On May 26 its blaze was 0.0150 volt, and on June 9 it was 0.0080 volt. During the whole time it gave off no hydrocyanic acid, as shown by the absence of discoloration of picrate of soda test-papers (Guignard).

There are different types of blaze currents, each part of an animal or plant having its definite and normal type. The type of blaze current is studied by means of Waller's A B C [2] method. In a laurel leaf, as in all other leaves, the blaze runs from external to internal surface.

All leaves hitherto tested have given the same type of blaze current. In response to excitation the blaze generally runs from the upper to the under surface, whereas in petals of flowers it runs 'homodrome' in the same direction as the exciting current. The blaze current runs from the growing point in stems towards more quiescent parts.

The blaze current is entirely a local phenomenon, and is confined to the exact area excited. A lilac leaf (chosen on account of its greater permeability and its lower resistance as compared with laurel leaves) which gave a blaze of 0.0300 volt was submitted to chloroform vapour by placing over part of its surface for one minute a watch glass on the under surface of which was stuck a piece of filter paper soaked in chloroform. The blaze was abolished at this spot, but was produced as before at other parts of the leaf. The exposure of such a leaf for one minute to air saturated with chloroform vapour is sufficient to kill the leaf, but it takes a longer time to kill a leaf immersed in a liquid saturated with chloroform.

[1] A. D. Waller, *Trans. Roy. Soc.*, vol. 194, B. 1901, p. 183.
[2] A. D. Waller, *Signs of Life*, 1903. John Murray, London.

In studying the blaze current of *Prunus laurocerasus* simultaneously with the evolution of prussic acid under the influence of chloroform I immersed a laurel leaf in picrate of soda saturated with chloroform for one minute and then tested the blaze current. One minute's immersion was not sufficient at the temperature of 40° C. to start the evolution of prussic acid nor to abolish the blaze current. A young leaf which gave a blaze of 0·0500 volt was immersed ten times for one minute and tested after each minute, it was then left in a moist tube for four days and it still blazed to the amount of 0·0010 volt. After four minutes in picrate of soda saturated with chloroform the leaf gave no blaze and smelt of prussic acid. The blaze is not abolished after two minutes' continuous immersion in picrate of soda saturated with chloroform at 40° C., nor after three minutes' immersion, but it is entirely abolished after four minutes, and the evolution of prussic acid is now beginning. A blaze current of 0·0200 volt was reduced to 0·0005 volt after three minutes' immersion at 40° C.

Blaze currents are more easily studied on young than on old leaves. Their more delicate cuticle offers a comparatively small resistance—100,000 to 200,000 ohms—whereas a full-grown laurel leaf, with its hard shiny surface, has a resistance of many megohms, and is thus an impossible subject to work with in its intact state. However, I found that by gently scraping off the thin external epidermis without causing injury the resistance was greatly diminished, and good blaze currents were then obtained.

There is a double process at work in all tissues, the polarisation effect and the blaze. The blaze is the sign of the actively living tissue, the polarisation goes on after its death. A perfectly fresh leaf will only show the blaze, but a leaf that is beginning to be abnormal will respond to excitation by a considerable polarisation current, which quickly subsides and gives place to the blaze current, which lasts five to ten minutes and subsides slowly. It is not easy to distinguish with certainty between an antidrome blaze current, which is a sign of life, and an antidrome polarisation current, which is a general physical effect. The difference in duration appears, however, to be characteristic. A blaze current is abolished by an anæsthetic; a polarisation current is not abolished.

Yellow Leaves.—As a laurel leaf fades it changes colour and falls. From dark green the colour is altered to light yellow. Is such a leaf alive or dead? The answer to this question is afforded by its blaze currents, which are unmistakably pronounced (0·005 volt); although the voltage is smaller than that of the blaze of a normal leaf, the galvanometer deflection is relatively large because a yellow leaf has a lower electrical resistance than a green leaf.

Presumably a yellow leaf is a dying leaf. It might, therefore, be expected to give off hydrocyanic acid independently of the action of anæsthetics. But, as a matter of fact, it does not do so; a yellow leaf, like a green leaf, does not give off any HCN in simple picrate solution, and it gives off little or no HCN in chloroform picrate, according as the fading is more or less complete. Yet a leaf that would be called completely faded, *i.e.*, in which the green colour has disappeared even

from its ribs, still exhibits a blaze current, while its capacity for evolving HCN under the influence of an anæsthetic has disappeared. The colour of such a leaf is changed from yellow to brown by the action of chloroform vapour.

The Effect of Climate upon Health and Disease.—Fourth Report of the Committee, consisting of Sir LAUDER BRUNTON (*Chairman*), Mr. J. BARCROFT *and* Lieut.-Colonel R. J. S. SIMPSON (*Secretaries*), Colonel Sir D. BRUCE, Dr. S. G. CAMPBELL, Sir KENDAL FRANKS, Professor J. G. MCKENDRICK, Sir A. MITCHELL, Dr. C. F. K. MURRAY, Dr. C. PORTER, Dr. J. L. TODD, Professor G. SIMS WOODHEAD, *and the* Heads of the Schools of Tropical Medicine of Liverpool, London, and Edinburgh.

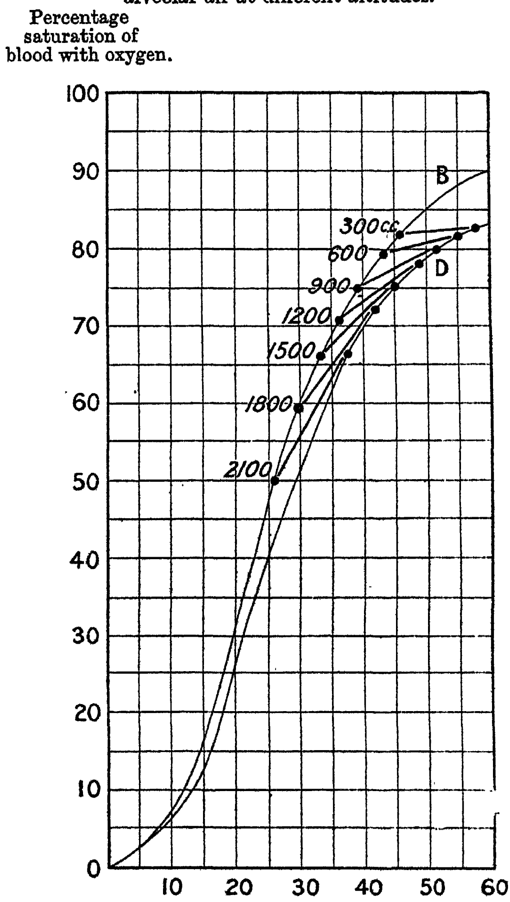
THE work produced by the Committee has consisted in a series of observations carried out in the island of Teneriffe on the subjects of the effect of altitude and solar radiation upon the organism. The Committee are only prepared to report upon the first of these subjects this year. The work was carried on at three stations, the altitudes of which were—sea-level, 7,000 feet, and 11,000 feet respectively.

The dissociation curves of four members of the party were studied, two completely.

The figure shows those of B and D. D's curves were investigated at a constant CO_2 tension equal to that of his alveolar air at the sea-level (41 mm. of mercury). At different altitudes it was found that the affinity of the blood for oxygen decreases progressively as the altitude increases. In point of fact D's CO_2 tension became progressively lower as the altitude increased, and therefore another series of curves was delineated in which the CO_2 tension was that of the alveolar air at the altitude in question. These curves coincided with one another and with the sea-level curve (D). The probable explanation of these facts is that as the altitude increases the carbonic acid is replaced in the blood by some most volatile acid, such as lactic acid, and that the total effective concentration of acid is the same throughout. The case of B. is somewhat different. B's dissociation curve remained the same throughout, as also did the carbonic acid in his alveolar air. Hence in his case also the total concentration of acid in the blood remained unaltered. The further question arises, Is it possible to explain the difference between the two types of reaction? In the first place, as shown by the figure, B's curve at the sea-level was somewhat different from that of D. The difference indicates a greater alkalinity in B's blood. Titration bore out this indication. In the second place, considerations based upon his respiratory quotient require that in proportion as the CO_2 tension in D's alveolar air was lower at 11,000 feet than in that of B, so D's oxygen tension was higher than that of B. Actual analysis showed this to be true. At 11,000 feet D had an oxygen tension of 63 mm. and B of 49 mm. In the third place, Krogh has shown that the oxygen tension in the

blood can be calculated from that in the alveolar air by subtracting 1 mm. for every 100 c.c. of oxygen absorbed by the lung per minute.

Figure showing dissociation curves of B and D at the CO_2 tension of their alveolar air at different altitudes.



The following table will therefore give the oxygen tension in D's and B's blood under varying circumstances of oxygen intake:—

O_2 absorbed per minute	300 c.c.	600 c.c.	900 c.c.	1,200 c.c.	1,500 c.c.	1,800 c.c.	2,100 c.c.
O_2 tension in D's blood at 11,000 feet	58 mm.	55 mm.	51 mm.	48 mm.	45 mm.	42 mm.	37 mm.
O_2 tension in B's blood at 11,000 feet	46 mm.	43 mm.	39 mm.	36 mm.	33 mm.	30 mm.	26 mm.

The degree of saturation of the blood with oxygen at the above tensions may be read from the figure. The point of interest is that, at rest (*i.e.*, using about 300 c.c. of O_2 per minute), B's blood and D's are about equally saturated. Hence, as B was careful not to take much exercise, his blood has had no occasion to compensate, he was in as strong a position as D, who had compensated. On the other hand, were increasing quantities of exercise taken, and increasing quantities of oxygen absorbed, B would be more and more at a disadvantage. These facts form at least an intelligible reason why B should have suffered from mountain sickness when he attempted to take exercise at 11,000 feet, whilst D did not.

Mental and Muscular Fatigue.—Interim Report of the Committee, consisting of Professor C. S. Sherrington (*Chairman*), Mr. W. MacDougall (*Secretary*), Professor J. S. MacDonald, *and* Mr. H. Sackville Lawson.

Professor MacDonald, of Sheffield, has been engaged especially on the physiological aspects of muscular fatigue as studied in isolated muscle preparations. A report of his results is presented herewith. He separates the phenomenon of contracture as a fatigue effect from that of diminution of the height of the contraction. He draws attention to the fact that fatigue muscle will do an amount of work similar to the amount furnished by a fresh muscle, with less attendant production of heat.

Mr. H. S. Lawson, of Wolverhampton, has worked on the examination of fatigue in schools, and has had a number of school teachers engaged in the observations.

It is urgently desirable that the Committee should be reappointed for another year in order to carry their investigations further.

Interim Report on Muscular Fatigue. June 1909. By Professor J. S. MacDonald.

Repeated excitation of exercised frog's muscle leads finally to a complete stage of exhaustion, during which a maintained state of slight contracture is present unbroken by any new contractile responses to continued stimulation. Prior to reaching this stage, the muscle yields contractions steadily diminishing in height and increasing in duration. These two modifications do not follow the same law of development. It is possible thus to secure a maximal degree of the one associated with a minimal degree of the other. Thus also the change in height of the contractions is arithmetically progressive, whereas the change in duration, increasing at first slowly, later proceeds at greatly increased pace. The later stages of this rapid development may be masked when the muscle is made to lift a maximal load, and such conditions may give rise to the still more complex appearance of a contraction-time, increasing at first and later diminishing.

In addition, a further and separable effect of previous activity is that initial increase in the height of contraction spoken of as Bowditch's 'staircase.' It is a common opinion that this phenomenon is to be observed in muscle in a fresh state. I have made certain of the fact that it is capable of demonstration, not near the final stage of fatigue, but at a surprisingly late stage of fatigue. Thus it is possible by the interpolation of a short period of rest and a subsequent renewal of stimulation, after fatiguing a muscle until it yields a contracture upon which each new response appears merely as an augmentation of this state, to observe this staircase phenomenon in a series of contractions, each of which is obviously of a very prolonged, and therefore fatigued type. Viewing the prolongation as symptomatic of a severe degree of fatigue, it is inconceivable that muscle in this state should contract to a greater degree save as the result of an increased excitation. It becomes necessary therefore to consider the possibility that the nervous impulse conveyed to the contractile material is modified by material within the muscle, and that conduction through this material is quantitatively facilitated by immediately antecedent use. The staircase phenomenon is quite possibly an affair involving the concoplasm, and not the contractile sarcostyles of muscle. In what degree a similar statement is applicable, not only to the initial increase but also to the later fall in the height of the contraction, remains an open question.

In order to simplify the investigation of such points, I have directed attention to the necessity for a connected conception of the facts of muscular contraction, and in a paper published in the 'Quarterly Journal of Physiology' I have endeavoured to supply a conception everywhere consonant with observed fact. According to the views there advanced, the relaxation of muscle is an active process reversing the conditions effective during contraction, and is to be regarded as a process of recuperation tending to reconstitute in the muscle a state favourable to the development of a subsequent contraction.

The increased duration of the contraction of a fatigued muscle, mainly but by no means entirely occupying the period of relaxation, is capable of treatment as due to a diminished recuperative p. ver. It is of interest therefore to place alongside of this statement the fact observed by all those engaged in the collection of measurements of heat production in excised muscle, that when fresh and fatigued muscles are made by adjustment of the stimulation to perform equal work fatigued muscle gives off less heat.

It is fair to assume that less combustion (*i.e.*, oxidation) has occurred because the store of combustible material is becoming exhausted. As a matter of fact, it has been shown that the presence of a smaller amount of such material does actually, without reference to rest or fatigue, diminish the amount of heat evolved during any standard contraction. Temporarily, therefore, it may be said that a fatigued muscle performs similar work, accompanied by diminished oxidation. It is absurd then to regard oxidation as the prime cause of contraction. It is, on the other hand, more probably a consequence of contraction, not so much in the forefront during fatigue. In the paper quoted above I have endeavoured to show that this is the case, and that oxidation, like

relaxation, is a recuperative process, which places a muscle that has once contracted in a position to contract again.

(1) Previous activity is then liable to modify the contraction process, as in the case of the staircase, by modifying the transmission of excitation through a muscle—that is to say, by modifying the mode of transmission of electrical charges. Since this transmission depends upon the electrolytes of muscle, we may look for modifications in these electrolytes as due to previous activity, and possibly responsible for many of the best-known incidents in fatigue.

(2) Previous activity also affects the store of combustible material within muscle, and so greatly modifies its recuperative power.

As to the manner of the recuperation, which is partially defeated by fatigue, it is possible that there are differences in such different cases as those provided by the muscle of cold- and warm-blooded animals respectively. When the recuperative processes of the relaxation period have done their work, there is still need for further recuperation. This is clearly seen in the case of frog's muscle. Thus, I have made sure of the fact, that even the second contraction of such a muscle is modified by the occurrence of the first to a demonstrable degree provided that it is observed within a certain period, much more prolonged than that of visible change, after the occurrence of the first. The second contraction is not only higher (staircase), but is even more clearly prolonged. Oxidations, accelerated by contraction, and these are the whole source of energy, are occurring in this later period of recuperation, just as also in the first recuperative period of relaxation, but are here more clearly seen as alone in action. In what form do such processes provide their energy? Conceivably this energy may be placed at the disposal of the muscle in the simplest way, as so much heat, or as some other form of energy.

It is in this connection that I have continued an investigation of the relation between temperature and the internal osmotic pressure of muscle, since contraction is probably due to variations in the distribution of this factor within the muscle, but so far without observing any corresponding change not similarly producible in any simple solution having none of the attributes of 'muscle.' This investigation has, however, still to be continued into the case of mammalian muscle.

It is clear that it would militate greatly against the average efficiency of the muscles of cold-blooded animals if their energy was delivered to them in the form of heat, and the only conditions determining an addition or an abstraction of energy were variations in external temperature. The muscle of the warm-blooded animal is more fortunately situated behind the protection of its constant temperature regulation, and is in a better position in this respect. The usual expectation is that muscle of this second class is more complex in its relation to its oxidative sources of energy. It is probable that the fact is the reverse of this, and that the warm-blooded muscle is more simple and does actually owe the physical condition of its internal solutions, upon which the phenomenon of contraction depends, to the heat provided by the processes of oxidation. That is to say, that it is conceivable that the maintenance of a constant temperature is also to be regarded as the maintenance of a constant bank of energy.

In this report I have endeavoured to make it plain that experimental fatigue is just such an experimental modification as facilitates a study of the processes of muscular contraction, and also explain the lines along which this study is being undertaken. The progress of the investigation is not sufficient to warrant any more direct form of statement.

Interim Report (No. 2).—Mental Fatigue in Schools. June 1910.
By Mr. H. Sackville Lawson.

This investigation, an outline of which was given in a previous report, was begun in November 1908. The experimental part of the work will have been completed by the end of July 1910.

The general object has been to discover what relation exists between the proved ability (relative) of a subject and his capacity for continuous work at high pressure; to discover, that is, whether an able boy is more resistant to fatigue than one less gifted.

The local Committee engaged on this investigation consists of three head-masters of elementary schools and the present writer. The number of boys experimented on is thirty, ten from each of the three schools. Each boy was within two months of nine years on January 1, 1909. The nature of the experimental work has been twofold. It has been the aim of the Committee—

(1) To obtain, by means of suitable tests submitted, a 'General Intelligence' Order of Merit for the thirty boys.

(2) To provide continuous work of such a nature and for such a period of time that fatigue effects may be shown.

Part I—*General Intelligence Order of Merit.*

Twelve tests have been given. The length of time for a single test has been from five to ten days. The Final Order of Merit has been obtained by aggregating the places obtained in the various intelligence tests. This Final Order is considered to be a hierarchy of Natural Intelligence. Incidentally it may be mentioned that a separate order of merit has been obtained by the ordinary scholastic examination methods. This has been found to correlate with the other to the extent of 0·61 where 1 = complete similarity of rank or identity of position.

Part II.—*Fatigue Tests.*

The general method of procedure has been as follows:—

Written work, generally of a mathematical nature, has been given for a period of half an hour per day. This half-hour has been taken either at the beginning or at the end of the school day. On the expiration of each five minutes a signal has been given in order that the output per period may be calculated. Thus there have been six consecutive periods each of five minutes' duration. The output in sums completed per period, as well as the number accurately done, has been calculated. Increase in rapidity and improvement in accuracy have been assumed to be due to the favourable influence of practice, while the reverse result has been ascribed to the inhibiting effects of fatigue.

Since 'Practice' and 'Fatigue' are forces opposed to each other, in that they react on the individual in contrary manner, it follows that the effect produced must be a resultant one. Where the urging forward tendency is strong the pushing back may yet be present latently. A 20 per cent. increase due to Practice would hide a 10 per cent. diminution due to Fatigue.

The figures given below represent the resultant generic effect produced by Fatigue Test A.

Period	Length	Number of Days	A Output (gross)	B Output (accuracies)	C Per cent. of Sums done Correctly
I	5 minutes	5	880	532	60·5
II	"	5	798	448	56·0
III	"	5	854	455	53·3
IV	"	5	804	438	54·8
V	"	5	790	406	51·0
VI	"	5	795	379	47·5

The figures in columns A and B represent the sum total of the efforts of twenty-five boys. Column C shows the accuracy output per hundred sums per period.

In the instance considered the worst period is the last, the best period the first. The coefficient of diminished accuracy is found [1] by subtracting the minimum value (47·5) after the maximum (60·5) has been obtained and dividing this number by the maximum value. Thus $60{\cdot}5 - 47{\cdot}5 = 13$; and $\frac{13}{60{\cdot}5} = 0{\cdot}2148$, or 21·48 per cent. where the number 100 represents absolute inaccuracy and 240 a condition of complete sustained accuracy. It is assumed provisionally that the falling off in accuracy is due to fatigue. In this manner the individual performances have been calculated and an order of merit has been obtained. The top boy in the order is he who shows the least susceptibility to fatigue, who maintains, that is, the steadiest output of accurate work period by period throughout the time allotted to the test.

The crude coefficient of correlation between this order and the Final Order of Intelligence is 0·22, or as a percentage of 22 where the number 100 represents similarity of rank or identity of position. When the order of merit (fatigue) is inverted, and the top place assumed by that boy who shows the greatest susceptibility to fatigue, as measured in terms of diminished accuracy of output, the coefficient of correlation is −0·28.

With regard to the other fatigue tests, the clerical work is not yet finished. They may, however, briefly be summarised as follows:—

Test A.—Addition sums. Two digit numbers. Five numbers in column. Thirty minutes a day for three days. Given at conclusion of school working day.

Test B.—Counting squares. Size $\frac{1}{64}$ of a square inch. Thirty minutes a day for five days. Given at commencement of school working day.

[1] Cf. *La Fatigue Intellectuelle* (Binet), p. 242.

Method.—Pencil dot is made in each square. Across every tenth square a diagonal is drawn. Unit effort is ten squares. Number of units marked noted per period.

Test C.—Multiplication sums. Five digit numbers multiplied by two digit numbers. Thirty minutes a day for two days. Given at conclusion of school working day. In each of these tests a signal was given at the end of each five-minute period in order that the output per period might be calculated.

Test D.—Dotting test. The machine which is being used is Dr. Rivers' modification of Dr. Dougall's apparatus.

The Committee hope to produce their report in December.

Body Metabolism in Cancer.—Report of the Committee, consisting of Professor C. S. SHERRINGTON (*Chairman*) *and* Dr. S. M. COPEMAN (*Secretary*).

CONSIDERATION of the curves of cancer mortality in the human subject, whether male or female, discloses the interesting and important fact that cancer is not, as is usually thought to be the case, a disease of old age, however much it may be related to senescence of certain of the body tissues. As a matter of fact, the disease is of extreme rarity in the later years of life, especially in the female sex. Thus the characteristic feature of the age incidence of cancer, as pointed out by Roger Williams and others, and as demonstrated by the returns of the Registrar-General, is not its continued increase with advance of years, but rather its disproportionate augmentation in the post-meridian periods of life—*i.e.*, between the ages of forty-five and sixty-five years—liability to the malady waxing as the reproductive activities wane. The facts, indeed, clearly show that cancer is *not* a disease of senility merely, which *per se* plays no part in its development.

In the animal world the age incidence of cancer is evidently governed by a similar law, as has been demonstrated by Stricker for horses and dogs, and by Bashford and Murray for mice; all these observers being in agreement as to the rarity of malignant tumours in early life and their relative frequency in later life, antecedent, however, to onset of old age.

In the light of these facts it would seem not improbable that the onset of malignant disease, whether in man or the lower animals, may have intimate relationship with diminished or perverted functioning of the reproductive organs, which, under normal circumstances, may be regarded as exerting—possibly by virtue of their so-called 'Internal secretions'—some restraining and co-ordinating influence on the growth of the somatic tissue elements.

Evidence of the existence of such a controlling influence is found in the fact, on which there is now general agreement among those engaged in the experimental investigation of cancer, that whereas transplantation of 'spontaneous' cancer in the mouse to normal individuals is apt to prove successful in but few instances when full-grown animals are employed for experimental purposes, complete insertion success has

not infrequently proved possible of accomplishment when mice of not more than six or seven weeks old are used. In view of the further fact that fanciers are agreed that the mouse is incapable of reproduction before the age of three months, while six months is generally stated to be the earliest age at which these animals should be mated in order to ensure healthy offspring, it would appear that the greatest measure of success in experimental implantation of cancer in this animal is obtainable only during the period of life antecedent to full or even commencing activity of the reproductive functions. On the other hand, implantation of cancer material from one mouse to another is *least* likely to be attended by success when the recipient is of an age at which these functions have attained the stage of full activity.

For these and other reasons it appeared desirable to investigate the question as to whether any of the products of the reproductive glands—presumably given off, under normal circumstances, in the form of an internal secretion—can be shown experimentally to influence, in one or another direction, the development of cancer as witnessed when this disease is experimentally produced in the mouse. For the prosecution of this investigation facilities have been most kindly afforded by the Executive Committee and the Director (Dr. Bashford) of the Imperial Cancer Research Fund, and the Committee is much indebted to them for a generous supply of material.

Although at the present time but little doubt exists as to the production of an internal secretion by the testes and ovaries, practically nothing is known of its nature and composition. It has, however, been suggested that its main constituent is in all probability derived from metabolism of nucleo-proteids which are present to so considerable an extent in the tissues of the reproductive glands. Professor von Poehl, of St. Petersburg, and others have, indeed, claimed that spermin, a crystallisable substance which has been isolated from the testes, prostate, ovaries, and in less amount from certain other organs and tissues, constitutes the essential principle in question. For the purposes of the present investigation, therefore, it appeared desirable, in the first instance, to make use of this substance (of which Dr. von Poehl, the successor of the late Professor von Poehl, kindly provided supplies), employing, in addition, freshly prepared emulsions of mouse testes, extracts of dried and powdered testes freed from nucleo-proteid, boiled watery extracts of the testicle of various animals, and a solution of nucleinic acid of orchitic origin. In every instance the action of all these various substances was tested on the mouse by hypodermic injection, while fresh emulsion of testes and solutions of nucleinic acid were also administered internally by a method of experimental feeding devised for the purpose.

For each series of experiments a number of mice were employed which had been inoculated with cancer material by a member of the staff of the Imperial Cancer Research Laboratories, from ten days to three weeks previously, by which time most of the animals had developed tumours, sometimes of considerable size, at the site of operation. The precise area of the resulting tumours in each animal is recorded on charts by one of the laboratory attendants ten days after implantation, and subsequently at weekly intervals. In every experiment one lot of inoculated mice was set aside as a control. Each series of experiments

has extended over a period of five or six weeks, or occasionally even more, so that the work has necessarily taken up a considerable period of time. Owing also to exigencies of the special work of the laboratory staff, and of official duties on the part of the member of this committee to whom the investigation was entrusted, delay in the prosecution of the work has from time to time proved unavoidable.

As the work is still in progress it would serve no useful purpose, on the present occasion, to enter into details of the numerous experiments performed. It is therefore proposed here only to set out a brief statement of the main results which thus far have been obtained.

As a preliminary step a number of mice were injected hypodermically with a 2 per cent. solution of spermin in normal saline solution, in quantities varying from 0·1 to 0·4 c.c., in order to make certain that the employment of this substance was not productive of any ill-effect on the mouse. This having proved to be the case with these doses, four mice which had been inoculated just previously with 0·05 grm. of tumour $\frac{63}{41\text{A}}$ in the left axilla, were subsequently injected daily, with the exception of Sundays, for a period of seventeen days, with 0·4 c.c. of the spermin solution. By this date three out of the four tumours which had arisen in these mice, as the result of inoculation, had entirely disappeared, while of eight tumours which had arisen in ten control mice, inoculated on the same date, *none* had disappeared, although two had somewhat decreased in size.

On February 4 of the present year twenty mice were inoculated with a very rapidly growing strain of tumour, of which ten were kept as controls in a separate cage. A week later tumours had appeared in all these mice. From this date, for a period of nearly three weeks, ten of the mice were injected daily, except on Saturdays and Sundays, with 0·4 c.c. of the spermin solution. As by this time the result obtained with the injected as compared with the control mice merely showed differences which might be considered as coming within the limit of experimental variation, the work was not continued.

In view of the apparent difference of result obtained in these two experiments, Dr. Bashford suggested that for future work it would be desirable to employ for purposes of inoculation a slow but continuously growing tumour (Twort 30B.), which, in this respect, most nearly reproduces the characteristics of a spontaneously occurring tumour. With this material Dr. Murray inoculated forty mice on March 4, of which ten were kept as controls, the other thirty being divided into three lots of ten each, and kept in separate cages. These were respectively injected daily—(*a*) with fresh emulsion of mouse testes 0·4 c.c. each; (*b*) with spermin solution; and (*c*) Poehl's orchidin solution in similar quantities. On March 21 eight tumours had developed in each lot of ten mice, while one of the controls had died. By April 4, of the spermin series, five of the tumours had disappeared; of the testicle emulsion series all eight tumours showed a definite increase in size; while of the orchidin series the tumours exhibited no appreciable difference from those of the controls. At this point the experiment was unavoidably interrupted.

In a further experiment on somewhat similar lines half the number of the experimental mice, in addition to being injected daily with spermin, had fresh testicle emulsion administered by the mouth. These latter, at the end of four days, showed a considerable diminution in size as compared with those injected with spermin only, one tumour of fair size having even at so early a stage of the experiment disappeared completely. Subsequently, however, possibly for the reason that the dose of spermin, which was larger than in previous experiments, was repeated too frequently, all the remaining tumours exhibited slow but steady increase in size up to the period when, three weeks later, the experiment was terminated.

In other experiments a testicle extract was employed which had been freed from nucleo-proteid, and which therefore contained, in addition to spermin, creatin and other extractives, as well as inorganic salts. The use of this material for the purposes of injection in a large number of mice eventually afforded no appreciable difference from the control mice as regards the size of the tumours, the result thus differing on the one hand from the definite increase obtained with the use of *fresh* testicle emulsion, and on the other from the diminution obtained in certain instances in which a solution of spermin was employed.

Certain of these experiments are now in process of being repeated, with large numbers of mice, by independent workers in the laboratories of the Imperial Cancer Research Fund, where also, thanks to the kindness of Dr. Bashford, a further series of experiments are also being carried out, in which nucleinic acid of orchitic origin is to be employed, both hypodermically and by oral administration—in the latter case both with and without the simultaneous use of hypodermic injections of spermin.

The Experimental Study of Heredity.—Report of the Committee, consisting of Mr. Francis Darwin (*Chairman*), Mr. A. G. Tansley (*Secretary*), *and* Professors Bateson *and* Keeble.

The grant of 30*l.* allotted at Winnipeg for this Committee has been used at Cambridge in connection with the researches carried on by Miss E. R. Saunders, Miss Wheldale, and Mr. R. H. Compton.

Miss Saunders' work on the inheritance of double flowers in stocks, wallflowers, hollyhocks, carnations, *Meconopsis*, *Petunia*, and other genera has been continued. Experiments on the inheritance of other characteristics have also been undertaken in various plants.

In the case of stocks it is hoped that from this year's results a material addition to the records of the last three years will be obtained, and that then it will be possible to give a full account of the work on the very complex problem which is here involved.

In the cases of the other plants named, most of which are biennial, the experiments have necessarily been lengthy, but it is hoped that the work of four seasons will shortly have reached a point at which a definite statement can be made.

Miss Wheldale is conducting experiments on the chemistry of pigmentation in plants, in continuation of her work already published.

Mr. Compton (Gonville and Caius College) is investigating the occurrence of sterility in the crosses between cultivated peas and a wild form brought from Palestine by Mr. Arthur Sutton. He is also conducting various other breeding experiments.

Clare Island.—Report of the Committee, consisting of Professor T. JOHNSON (*Chairman*), Mr. R. LLOYD PRAEGER (*Secretary*), Professor GRENVILLE COLE, Dr. SCHARFF, *and* Mr. A. G. TANSLEY, *appointed to arrange a Botanical, Zoological, and Geological Survey of Clare Island.*

SINCE the last report was presented, twelve months ago, much work has been carried out on Clare Island and the adjoining mainland as regards both the fauna and the flora. Among the groups that have received special attention are: Sponges, polyzoa, insects (many orders), mollusca (marine and fresh-water), birds, algæ (marine and fresh-water), lichens, fungi, mosses, and hepatics. In addition, meteorological observations have been commenced; also the investigation of the peat deposits. The work is going steadily forward, and it is hoped that it will be completed by the end of 1911. As reported in the statement of accounts, the grant made by the British Association will not carry the work through, and further assistance would be very welcome; for the present the Committee are using other funds which they have been successful in procuring.

The Structure of Fossil Plants.—Report of the Committee, consisting of Dr. D. H. SCOTT (*Chairman*), Professor F. W. OLIVER (*Secretary*), Mr. E. A. NEWELL ARBER, *and* Professors A. C. SEWARD *and* F. E. WEISS.

THE amount granted has been fully spent on sections of *Stigmaria* for the continuation of Professor Weiss's investigations and on sections of various plants from the roof nodules (which contain a characteristic flora of their own) for Professor Seward.

Mr. H. H. Thomas has made great progress with his work on the structure of the leaf in Palæozoic plants, referred to in the last report. He has published a preliminary statement 'On the Assimilating Tissues of some Coal Measure Plants' in the 'Proc. Cambridge Phil. Soc.,' vol. xv., pt. v., 1910, and an extensive paper on the leaves of *Calamites* will shortly be communicated to the Royal Society.

Mental and Physical Factors involved in Education.—Report of the Committee, consisting of Professor J. J. FINDLAY (*Chairman*), Professor J. A. GREEN (*Secretary*), Professor J. ADAMS, Sir E. BRABROOK, Dr. W. BROWN, Professor E. P. CULVERWELL, Mr. G. F. DANIELL, Miss B. FOXLEY, Professor R. A. GREGORY, Dr. C. W. KIMMINS, Mr. T. LOVEDAY, Dr. T. P. NUNN, Dr. SLAUGHTER, Mr. BOMPAS SMITH, Dr. SPEARMAN, Mr. TWENTYMAN, Miss L. EDNA WALTER, *and* Dr. F. WARNER, *appointed to inquire into and report upon the methods and results of research into the Mental and Physical Factors involved in Education.*

IN their Report for last year, your Committee drew attention to the great movement towards the independent investigation of pedagogical problems which is going on all through the civilised world. They pointed to the foundation of institutions for pedagogical research in Antwerp, Milan, Leipsic, St. Petersburg, Moscow, and elsewhere—institutions with special funds available for the prosecution of pedagogical inquiries—and in addition to these they showed the trend of interest among many Continental and American psychologists towards problems that concern the schoolmaster very closely.

This new field of inquiry is the natural outcome of the successful application of experimental methods to the investigation of mental phenomena, but it is, in the Committee's view, important to understand quite clearly whether or not there is a body of doctrine which can be separately regarded and called the science of education, or whether the schoolmaster's practice is to be based on contributions from various branches of science without any common centre of reference which shall give them the inner unity which belongs, for example, to such a science as agriculture. It seems to your Committee that the particular point of view from which Education interprets its subject-matter is so distinct from the points of view of the psychologist and the sociologist for example, in dealing with the material of their sciences, that the independence of the science of education must follow, if, indeed, the existence of this Section of the British Association is not already an admission of its claim.

Until the present time, however, although much has been written upon educational theory and educational procedure, there has been little or no attempt to deal with its materials in a scientific spirit. Its facts have not been collected in any orderly way; tradition, rather than the results of independent observation, has guided the schoolmaster in his classroom. The *à priori* view has dominated the mind of the educational reformer; he has, indeed, been most concerned with the question of the end to be reached, interpreting thereby the current philosophical and religious notions of his time in educational terms. The study of the persons to be educated and their attitude towards methods of instruction was left aside; it was sufficient to rely on the sympathetic

intuitions of the schoolmaster. The position was unassailable so long as mental behaviour was regarded as something lying beyond the reach of exact objective methods of inquiry. The psychologist and the alienist have taught us that this is not the case. The application of mathematics to the solution of its problems is the latest indication of the probability that, in the last resort, mental phenomena are as obedient to law as the things of the material world.

In response to the request of your Committee, various gentlemen whose names are well known as investigators in this field have expressed their views of the importance of the work.

Professor Binet, of the Sorbonne, writes, after showing how the artist's study of anatomy should differ in character from that of the doctor, because their object is different:—

I think the same holds good in regard to the relations of psychology and pedagogy. We shall gradually learn what the real needs of teachers are. Abstract psychological knowledge is of no use to them. They require knowledge of quite a special character, such as will find an immediate application in instruction and education. They should have at command the means of recognising intellectual and moral types amongst children; means of measuring memory and of strengthening it; they should know how to estimate fatigue and how to counteract it. But few, if any, of the psychological treatises of the last twenty years satisfy a demand of that kind. It is therefore necessary for psychologists and teachers to set themselves to the task of creating a science, 'psycho-pedagogy,' which, at the present moment, does not exist. In pursuing inquiries of this kind it is essential that we should not lose sight of their object—namely, that of finding out things that will be useful to a teacher acting in his professional capacity. Everything which is not related to that end should be rigidly excluded.

Professor Claparède, the fourth edition of whose book 'Psychologie de l'Enfant et Pédagogie experimentale,' is now in the press, has written as follows:—

The means which must be employed by the educator are not given *à priori*; they are the outcome of experience. He is concerned in fostering and directing the development of his pupils and in imparting knowledge to them. It is therefore essential that he should know how this development takes place and how the knowledge he would impart is assimilated. These things science alone can teach us.

The fact that human possibilities are increasing every day without any corresponding increase in the length of human life makes it more and more important to see that our systems of education are as economical and fruitful as possible. The pupil has neither time nor energy to fritter away. The science which can do most for the educator in this matter is the psycho-physiology of children. Such a science is as necessary to the teacher as physiology to the physician. This is so obvious that we need not labour the point.

Some will urge that the experience which is admittedly essential can only be gained by practice. 'It is only by teaching that a good teacher will be made.' It is, of course, true that practice is essential to success in any art, but in this particular case it is surely necessary to reduce to a minimum the period of apprenticeship. The teacher who is left to master his art without any knowledge of the material on which he is working is reduced to experiments in which his pupils suffer. Not unfrequently these experiments are very long and very injurious to generations of pupils who undergo them. Practice may in time make up for a want of theoretical knowledge, but the price paid for the period of ignorance is incalculable. What is still worse, the injury done is irreparable. If an incapable engineer builds a bridge which collapses the damage can probably be repaired—at any rate, the bridge can be rebuilt; not so a human mind.

It is hardly necessary also to point out that practice makes many bad teachers.

Their pupils' dislike marks their want of success; they themselves are embittered, and their influence is like that of a withering blast upon the vital energy of young plants. All this might have been avoided if the teacher had from the beginning known how children must be treated if they are to be his friends, and how to present the material of instruction in order to stimulate their interest instead of filling them with disgust.

An experimental pedagogy is therefore an essential. It includes psycho-pedagogy, medico-pedagogy, and the hygiene of teaching. Here we are only concerned with psycho-pedagogy, that is the psychology of the child applied to pedagogy. This science aims at furnishing the educator with a means for *diagnosis* and *prognosis*. Is this child intelligent? Is he backward? What are his dominant capacities? Is his bad work due to idleness, boredom, fatigue, or some passing disturbance? These are typical problems for diagnosis.

What career shall this youth follow? Given his present capacities, can we foretell his future aptitudes? In what sort of post will he make the best use of his powers? These are questions which belong to what I have called psycho-prognosis.

Psycho-pedagogy will also aim at providing the teacher with a right technique. It seeks to answer such questions as, How is judgment developed? How can over-pressure be avoided? When should we begin to teach a child to read? How should the will be trained?

It will also embrace other problems which concern particular subjects of instruction—an 'experimental didactic.' How should the beginnings of number be taught? What is the right way of teaching modern languages? &c.

Dr. Schuyten, Pædologist to the City of Antwerp, himself the author of many researches concerning the child at school, has sent the following communication:—

Pædology is the synthesis of all the sciences which contribute to the exact knowledge of childhood. It draws its data from hygiene, anthropology, physiology, normal and abnormal psychology, pædagogy, and sociology. We have abandoned the idea, still not uncommonly held amongst schoolmasters, that the child is not a subject for accurate objective study. We know that his various activities, mental and physical, may be accurately measured, and that when teachers have realised this and have themselves been more scientifically educated, they will be in a position to understand and appreciate the possibilities of the subject.

We are now in a period of transition, but the surprising number of researches published in recent years already make it possible to indicate certain general lines of work which I may condense as follows:—

A. (1) The great development of the biological sciences has shown that the experimental investigation of children may give more exact bases for the educational treatment of childhood.

(2) It has been shown that the child must be considered as a biological object, obeying the same natural laws as other forms of organic and inorganic matter. Thus scientific investigation is possible and inevitable if we would obtain accurate data for educational procedure.

B. It is possible at present to determine accurately

(1) The hygienic conditions for the sound treatment of children (ventilation, lighting, warming, &c.).

(2) The physiological bases of nutrition, movement, work, overwork, and fatigue.

(3) The anthropometric laws concerning normal and abnormal physical development.

(4) Mental data derived from normal and abnormal children and from animals, from which the laws that underlie psychological phenomena may be discovered.

(5) The sociological phenomena of early life as observed in civilised and uncivilised peoples and in animals.
(6) The educational applications resulting from the foregoing, as seen in the school, the family, and in Nature.

No science has in the past developed so rapidly as pædology. Its great importance was immediately and universally recognised, as we see from the fact that so many and so various institutions devoted to this subject have already been established. I can count on the spur of the moment in Europe alone sixteen Child-Study Associations, twenty-one reviews devoted to Child-Study, eleven laboratories and institutes of pædology, and no fewer than eight congresses on various aspects of the subject have already met. In North and South America and in Japan the number of societies and journals is very great, but unfortunately little known.

It is easy to foresee that in no very remote future the majority of the universities of the world will have established pædological courses with laboratory arrangements on thoroughly scientific lines.

These communications sufficiently indicate the importance which is attached to the subject in France and in Belgium, an interest which, in the latter country, has led to the establishment of an official body, L'Institut National Belge de Pédologie, which, under the presidency of the Directeur-Général de l'Enséignement primaire, is organising systematic work on a large scale. The new society has already established a journal, 'Les Annales Pédologiques,' which made its first appearance in October 1909, since the last meeting of the Association.

In our own country we may note in this connection the forthcoming appearance of a new journal, 'The Child,' which is a welcome sign of the growing interest in educational and other allied researches, and the widespread activities of the British Child Study societies continue to increase in importance.

In view of the large amount of work being done in other countries, the Committee set out to inquire what was actually being done here, and what special resources were actually available. They knew of nothing to correspond with the Pædological Laboratory at Antwerp, but it was clear that the psychologists were beginning to take the matter up and that possibly more was going on than was generally known. Their inquiry shows that special funds are rarely available; such work as is being done is chiefly in the hands of students who are working in the first place for academic recognition. Here and there privately interested people are working on their own initiative and at their own expense; otherwise inquiries are being for the most part conducted in the available time of university teachers, who are already occupied with the general direction of a laboratory or in doing other teaching work.

The replies to the Committee's inquiries may be summarised as follows:—

From Cambridge, Dr. Myers writes that no special funds are available, but that various researches in the psychology of school children are being carried on. These researches are concerned with geometrical optical illusions, colour vision, and colour vocabularies, memory (rational and mechanical learning), &c. One research has just been completed, continuing the work of Ziehen and others on Mental Association in Children. The possibility that psychology may be made

an optional subject for the ordinary degree may stimulate interest in the subject and lead to systematic inquiry by individual students. It would, in Dr. Myers' view, be of the greatest advantage to the cause, if systematic co-operation between psychologists and pedagogical experts could be secured.

From Oxford Dr. McDougall says that there are no funds for the support of the laboratory in which his psycho-physical work is done, although an initial grant for its equipment was made from the University chest. The work of the laboratory is not specially directed to educational problems, although its students have prosecuted inquiries having important educational bearing, as, for example, Mr. C. L. Burt's work on 'Intelligence,' an instalment of which appeared in the 'British Journal of Psychology,' December 1909.

Professor Karl Pearson reports that a great deal of systematic work is being done in the Biometric and Eugenics Laboratories of University College, on the influence and relation of mental and physical characteristics of school children to each other. The data at present available deals with a hundred thousand children from all classes and localities. The laboratories are each endowed to a small extent with funds which enable them to undertake and publish statistical work of this kind, but with more money much more might be done.

In the Psychological Department of University College, under Dr. Spearman's direction, research work, especially in connection with education, has developed with surprising rapidity. Two investigations are almost complete and two are well started, dealing with various aspects of memory. Another is practically finished on the problem known as 'Transfer of Training.' One is just being concluded on the powers and the diagnosis of mentally defective children. Further work is being started on 'Imagination' and on 'Mental Inertia' respectively. Altogether, as much is being done as can be properly supervised by one director. No lack has so far been felt, either of research facilities or of able students, but only in respect of most of the students' previous training in psychology. This has been little adapted for grappling with actual scientific problems; in fact, it has often been of a character that should now be obsolete.

Dr. W. Brown, in the Psychological Department of King's College, has on hand researches concerning the measurement of simple mental functions of school children and students in training colleges; he is following this up by correlating the results with each other and with different measures of intelligence, using the general theory of *multiple correlation* as a means of evaluation. Dr. Brown has given courses of lectures on Experimental Psychology as it concerns the school child to audiences of teachers during last session, and a course on 'Statistical Methods in Psychology' preparatory to research work in the schools, which is to begin next session. This research work has special reference to the Higher Diploma in Pedagogy which has been recently instituted by the University of London.

From Bedford College, Miss Edgell reports that a student is working in connection with the Physiological Laboratory of the University on the problem of Fatigue in school children. At the College itself

researches on children's methods of memorising poetry and the distinctions between apperceptive and chance associations are going on. No special funds are available.

In the Northern Universities the work at Manchester, under Professor Findlay, has been more directly concerned with the organisation of school activities in the light of general principles of a biological and sociological nature. The recent appointment of a lecturer in Experimental Psychology in the University will probably secure just that co-operation which Dr. Myers desires to see established.

In Liverpool Mr. Burt is continuing his work on Experimental Tests of 'General Intelligence,' and the following further researches are also proceeding: (1) On the Determination and Influence of Ideational Types in Children; (2) on Mental Differences between the Sexes (at present concerned mainly with sensory acuity, reaction times, attention, memory, and emotions, both in children and adults); (3) on the Inheritance of Simple Mental Characters (correlation between sensory discrimination and reaction time in parent and offspring); (4) on the Transferability of Improvement (symmetrical transference—'cross-education'—with practice at cutaneous discrimination and tapping, and its correlation with improvability in higher capacities).

There are no special funds available at present, either for apparatus or for the encouragement of research students. Considerable spontaneous interest is, however, being shown by teachers, inspectors of schools, and social workers.

In Sheffield the Department of Education is provided with a small psychological laboratory, and a small grant is made by the University authorities for its maintenance. During the last session a careful practical application of Binet's Intelligence Tests has been made and will be reported on at this meeting. A research on the schoolboy's mental reactions to current geography instruction is being prosecuted, and a student was engaged during last session upon an inquiry into the psychological differences amongst a small group of sub-normal children. A course of lectures on 'Modern Methods of Child Study' was given by the Professor of Education during last session.

In Scotland connection between experimental psychological methods and the study of education is so far recognised that students in training in Edinburgh must take a course which includes at least a term's work in the psychological laboratory. The new building for the Training College is to contain a laboratory, and, in the meantime, simple experimental work with simple apparatus is being carried on. Two investigations are at present in progress—one concerning the connection between the rate of reading a passage and its comprehension—and in the demonstration schools experiments are being carried on in the endeavour to determine the main apperceptive types.

In Aberdeen Mr. J. Lewis McIntyre, the Lecturer in Comparative Psychology, takes the psychological work of the students in training. He is at present engaged on experimental work bearing upon the study of memory in children of different ages and conditions. He notes especially the great need of funds; the present preliminary work is done at the expense of the lecturer.

In Glasgow the resources of the Department of Psychology are open to students who are interested in educational investigation of a psychological character. Dr. Watt's work on Memory and the Psychology of Thinking is well enough known to indicate the various directions which that might take.

Under the inspiration of Mr. W. L. Winch, the Teachers' Guild has formed a Research Committee, which receives and discusses abstracts from the psychological journals, and assists in the prosecuting of research in the schools. Mr. Winch has devoted himself to work of the kind for several years, entirely at his own expense. He has already published many papers on the subject, and last winter he gave a course of lectures, under the auspices of the London County Council, dealing with the results of the experimental investigation of educational problems, not only so far as they concern the teacher, but also those of the administrator—*e.g.*, the relation between bodily growth and mental progress in schools, athletics and school progress, when children should begin school, &c.

Mr. H. S. Lawson, of Wolverhampton, has also conducted important inquiries partly in connection with the British Association and partly privately. His private inquiries aim at (1) obtaining a hierarchy of coefficients of correlation for tests which 'tap' the higher mental levels; (2) showing that simple mental tests designed to expose natural ability (inborn) are a better criterion of merit than the ordinary official examination which is prescribed for boys who desire secondary education, and who present themselves for the scholarship examination at Wolverhampton Grammar School.

This review of the present position of the movement towards research into educational problems is necessarily incomplete. It considers the subject from a point of view which many will consider very partial and tentative, and, even within that narrow range, probably much has escaped its attention. Nevertheless the report shows that a considerable amount of work is being done in almost all the directions in which out-of-school research can help to solve the teacher's problems—the psychologist in particular is busy with investigations which concern the process of instruction very intimately. Indeed, it seems almost necessary to point out that there is just a danger of forgetting the sociological and ethical aspects of the educational problem—aspects not less important than the psychological. The whole field of experimental pedagogy has been virtually left out of account in this review, and, although we may expect to gain much by a study of the results of laboratory work, it is, in the Committee's view, quite likely that the gain to educational science will come as much from a study of the methods of the laboratory worker as from his achievements. In any case, those results will have to be selected and adapted to the special needs of the teacher and to the actual conditions of class-room work before they can be incorporated into any systematic body of doctrine which will in the future stand for the science of education. But class-room investigations that will bring results of any permanent value must be conducted with as near an approach to the rigours of exact science as the conditions will

allow. It is in the hope of its producing a body of teacher-workers, capable of conducting investigations of that kind, that the present tendency to give to the teaching of pyschology a more practical and experimental basis should, in the Committee's view, be welcomed. They have drawn up, as an appendix to their report, a list of typical problems which seem to them to call for systematic inquiry.

The Committee wish finally to draw the attention of the Section to the urgent need for funds in the furtherance of educational research. The work is being done at present in this country under severe handicaps, both of time and money. So much is being accomplished in Europe and America that the national honour seems almost at stake. When may we hope to see such an institution as Teachers' College in our country—a great institution devoted to advanced pedagogical study and research? At least, in their view, the subject should be regarded as ranking with medicine and other University studies in this respect, and as needing the same financial support for purposes of research as other departments of knowledge. The needs of departments of education in Universities are apt to be overlooked by the Treasury, which considers them already provided for from other funds, but grants from the Board of Education at present cover tuition fees only; they take no account whatever of the need for research.

In conclusion, the Committee express the hope that they may be reappointed, to consider and report upon developments in the direction which they have described.

APPENDIX.

Typical Problems for Research in Education

A. *Questions of a Psychological Character.*

(1) The child as an observer—how far is he dependent upon inner factors for his direction?

(2) The capacity of children of various ages for receiving and resisting suggestion (*a*) from the teacher; (*b*) from books, pictures, physical environment; and (*c*) from other children. Contra-suggestion.

(3) The active and the passive type of child—their psychological characteristics. The possibility of determining other types.

(4) The varieties of imagery in the mental life of children, and its relation to methods of instruction—image types.

(5) The relation of the child's vocabulary to his mind-content, as shown (i) by his spoken (ii) by his written words and sentences.

(6) The development of children's memory powers—types of memory.

(7) Attention—the problem of its development—types.

(8) Mental elaboration—association—the development of general ideas—ways in which children reason.

(9) The child's motor activities—the psychology of the child draughtsman—expression and representation—conventions and symbols—when do they appeal to the child?

(10) The psychology of the processes of reading, spelling, writing, number-work, &c.

(11) The psychological differences in children—normal and sub-normal—the question of psychological diagnosis. Sex differences—are they fundamental or due to circumstances and training?

(12) The study of intelligence:—

(i) Special forms of intelligence.
(ii) The correlation of general intelligence with specific mind functions.
(iii) Intelligence and age—averages.
(iv) Tests of ability.

(13) The problem of formal training.

(14) The development of moral, religious, and æsthetic instincts, habits, and ideas in children.

(15) The psychology of children *en masse*. The educational influence of

(i) The corporate life of school.
(ii) Self-government.
(iii) School or class customs and traditions.
(iv) School games.

(16) Character and temperament:—

(i) The determination of types.
(ii) The classification of defects.

(17) Differences of ability in various social classes.

B. *Questions of more direct Pedagogic Character.*

(1) The more careful psychological analysis of the ideas involved in special school subjects—and the general problem of 'psychologising' instruction in them; *e.g.*, history, geography, mathematics. The relation of the logical to the psychological treatment of the subject.

(2) 'Economy' in methods of teaching various subjects.

(3) The relation of the curriculum to the individual child having regard to (i) its special abilities, (ii) the probable length of its school life, (iii) its future calling.

(4) The question of promotion—special treatment of dull and quick children.

(5) Fatigue. Length of school hours.

(6) Value of physical and manual training of a formal kind.

(7) Co-ordination of home and school life.

C. *Questions of Sociological Character.*

(1) Influence of schooling on the fluid organisation of society.

(2) Effects of education of different types on the moral condition of the community.

Corresponding Societies Committee.—Report of the Committee, consisting of Mr. W. WHITAKER (*Chairman*), Mr. W. P. D. STEBBING (*Secretary*), Rev. J. O. BEVAN, Sir EDWARD BRABROOK, Dr. J. G. GARSON, Principal E. H. GRIFFITHS, Mr. T. V. HOLMES, Mr. J. HOPKINSON, Mr. A. L. LEWIS, Professor R. MELDOLA, Mr. F. W. RUDLER, Rev. T. R. R. STEBBING, *and the* PRESIDENT *and* GENERAL OFFICERS. (*Drawn up by the Secretary.*)

THE Committee beg leave to recommend that the Bournemouth Natural Science Society and the Torquay Natural History Society be placed on the list of Affiliated Societies, and that the Hull Junior Field Naturalists' Society and the Llandudno and District Field Club be placed on the list of Associated Societies. An application has also been received from the Hampstead Scientific Society for affiliation as possessors of a second-class meteorological station, but could not be allowed under the rules of the Association as the records obtained were not published in the Society's proceedings.

The Committee recommend that the Halifax Scientific Society, as it has found itself unable to continue the publication of its Journal, should be removed from the rank of an Affiliated to that of an Associated Society. The Bath Natural History and Antiquarian Field Club, and the Manchester Field Club, owing to their discontinuance, are removed from the list.

The Committee have received applications for literary help from the Birmingham Field Naturalists' Club, an outside society, so as to ensure the continuance of its recently started magazine; and for monetary help from the Bradford Scientific Society, which finds itself unable to continue its quarterly journal without outside help. The Hon. Secretary informs the Committee that the Society has lost 60*l.* through this journal in the last six years.

Dr. Tempest Anderson has promised to preside at the Conference in Sheffield, and to deliver an address to the delegates.

The Committee have decided that the following subject be brought before the Conference for discussion:—

'That a Committee of Biologists be formed to recommend the adoption of a definite system on which collectors should record their captures.' To be introduced by Mr. F. Balfour Browne (Belfast).

Other subjects for discussion have been suggested by the Dumfriesshire and Galloway Natural History and Antiquarian Society and the Liverpool Engineering Society, which it is hoped their delegates will introduce.

The Committee ask to be reappointed, but with the name of Dr. A. C. Haddon in place of Professor R. Meldola, who has tendered his resignation. The Committee also apply for a grant of 25*l.*

Report of the Conference of Delegates of Corresponding Societies held at Sheffield on September 1 and 6, 1910.

Chairman	Dr. Tempest Anderson.
Vice-Chairman	Prof. P. F. Kendall.
Secretary	W. P. D. Stebbing.

FIRST MEETING, *September* 1.

The meeting was presided over by Dr. Tempest Anderson, Chairman of the Conference. The Corresponding Societies Committee was represented by the Rev. J. O. Bevan, Sir Edward Brabrook, Dr. J. G. Garson, Mr. T. V. Holmes, Mr. W. P. D. Stebbing, and Mr. W. Whitaker.

The Chairman, after the Secretary had read the report of the Corresponding Societies Committee, opened the Conference by giving the following Address and a demonstration on some methods of optical projection.

Chairman's Address.

It is understood that the Sections deal with results of investigations in various branches of science, while this Conference is concerned chiefly with methods of conducting such investigations, and especially in co-ordinating the efforts of our Corresponding Societies in carrying them out. I think we may fairly include in our programme methods of demonstration of such results before audiences, large and small, as questions relating to these constantly force themselves on the officials of scientific societies. I propose, therefore, to speak on some methods of optical projection to which I have paid attention for many, I am afraid to say how many, years.

At the meeting of this Association at Aberdeen in 1885 I read a paper in Section C on the 'Volcanoes of Auvergne,' the abstract of which in the Annual Report begins as follows :—

'The modern dry-plate process of photography has placed in the hands of geologists the power of rapidly and faithfully recording and reproducing before an audience of any size many geological, and especially volcanic, phenomena which it would be impossible adequately to describe in words.

'By means of the oxyhydrogen lantern a number of photographs which had been taken by the author in the volcanic district of the Auvergne and adjacent parts of the Velay and Vivarais, in Central France, were shown on the screen.'

This now reads like a truism. It was then a novelty, and I remember the then President of the Section (Professor Judd) remarking that he thought the process employed might be of value in recording geological, and especially volcanic, facts. Unfortunately the Annual Reports do not contain any account of the discussions following papers, so that I am unable to quote the exact words.

Three years later, at the Bath Meeting, I read a similar paper on the 'Volcanoes of the Two Sicilies,' which was also illustrated by lantern photographs of Vesuvius, Etna, Stromboli, and Vulcano, and at the same meeting Mr. Osmund W. Jeffs read a paper on 'Local Geological Photography,' in which he urged the importance of the new method. The result was the appointment at the next meeting, at Newcastle in 1889, of a 'Committee for the Collection, Preservation, and Systematic Registration of Geological Photographs,' the valuable results of whose labours are known to you all.

Projection of lantern photographs is now the recognised method of lecture illustration, and needs no further recommendation: 'Good wine needs no bush.'

There are, however, cases when the object to be described is of small size, and where it would be convenient to show an image of the object itself.

Opaque Projection.

Many attempts have been made to produce an instrument which would project on the screen an image of opaque objects not larger, say, than a postcard, the

image to be of a size, brightness, and definition sufficient to render it visible to an audience. In most of the earlier apparatus the object was illuminated by limelight concentrated on it by an ordinary condenser, and was placed upside down and vertical, so as to be parallel to the screen, on which the image was projected by a lens, with its axis horizontal. This arrangement gave an image which was correct when viewed through a semi-transparent screen, so that the lantern had to be behind the screen. If it were placed in front in the usual way the image could be obtained right way up by the ordinary method of inverting the object, but in that case it was inverted from side to side, like the image of a person as seen by himself in a looking-glass. This rendered labels and all printed and written descriptions illegible, and made the apparatus useless for showing diagrams and figures in books. This difficulty can be got over by reflecting the rays on their way to the screen by a plane mirror, which produces a similar error in the other meridian, so that the whole can be set right by altering the position of the object. The optic axis of the lens can also be kept vertical, and the object lies flat, which is a great advantage for small, loose objects on trays, such as fossils, or coins and medals.

I employed this device in an instrument I devised and had constructed in 1905-06 before the British Association Meeting at York. A lantern was required to project photographic slides on a very large screen so as to be visible to an audience of, say, 1,500 or 2,000 at the evening lectures. It was decided to make one with every item the best possible. I had an old Dalmeyer portrait lens that was very suitable for the front projection lens, and it was found on inquiry and experiment that a condenser with a meniscus as the back lens gave the best results. Such an one was procured, and this completed the optical part of the outfit. It remained to obtain an electric lamp that would give with the 200-volt town supply the most powerful and steady light available. Mr. Hame, of the Corporation Electric Department, and his junior, Mr. Foster, were at much trouble in getting such an one which had been found reliable. It had a hand feed. These components were all plotted in their places on paper and a lantern drawn round them. The lantern was made by a local joiner and worked perfectly the first time it was tried. It is the best and most powerful one I have seen, except perhaps that at the Alpine Club in London, where the different components were selected separately by various experts in a similar manner.

I tried to combine an apparatus for opaque projection with this by using the very powerful horizontal beam of light issuing from the condenser and turning it down on the opaque object by a plane mirror. The light, as it came off from the object, was collected by a rapid portrait lens, placed vertically, and reflected on to the screen by a mirror as described above. The image appeared right way up, right side forward, and of suitable size, and the result was thus satisfactory as showing that our optical calculations were correct; but the loss of light by reflection from two mirrors and from the object, besides that by passing through several pieces of glass in the condensers and lenses, was so great that the attempt was abandoned for the time.

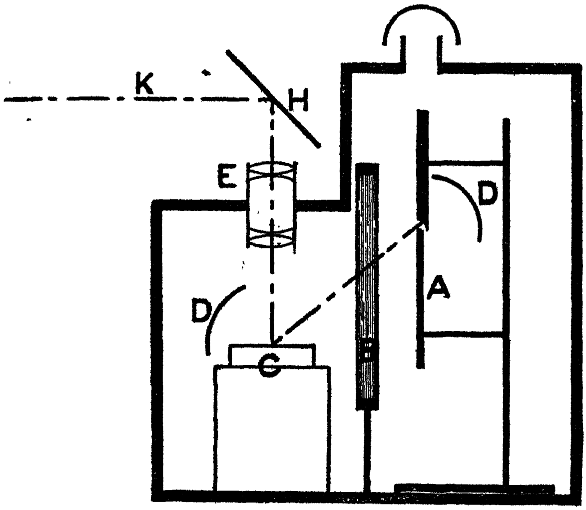
It will be remembered that the voltage necessary for a single arc light is only 40 to 50, and if a current of a higher pressure be used, which in our case is 220 volts, it is necessary to introduce a resistance which reduces the amount that can pass, and converts the surplus energy into heat which is wasted.

In the spring of this year I saw an account of a new lamp invented by Mr. Beardmore, and made by Marion & Co., which would work four arc-lights in series with one current, used four times over; only a very small resistance was thus required to steady the flow, so that practically all the power was utilised. The arcs being arranged in close proximity give a very brilliant light without a condenser, and a concave white screen behind utilises much light that would otherwise be wasted.

Mr. Hame was again kind enough to order the proper size of lamp, while Mr. Foster again superintended the practical fitting. The result is that we get four powerful arcs almost close to the object, which is thus intensely lighted, and the light from it is taken up as before by the lens and mirror and focussed on the screen. No advantage was found by the introduction of condensers, which, moreover, rendered the light streaky and uneven.

Several opaque objects, such as a watch face, pencil diagrams on a porcelain slate, pieces of polished marble, and small fossils, were shown satisfactorily on the screen. It is hoped that the use of a water-tank with glass sides may reduce the heat sufficiently to enable natural history specimens to be safely shown.

The accompanying sketch shows diagrammatically the general arrangement of the apparatus in side elevation.



A, Four-arc lamp in profile; B, cooling tank; C, object on adjustable block; D, concave white screens; E, rapid portrait lens; H, plane mirror; K, path of rays to screen.

The thanks of the meeting for the Chairman's valuable address and demonstration were proposed by Professor P. F. Kendall.

Mr. A. Archibald (Tunbridge Wells Natural History and Philosophical Society), in seconding the vote of thanks, said that he would like to mention that a simple form of instrument upon the principle of the aphengescope will be found of great value in the class-room, but to place the image in its correct position the lantern and reflector attached should be placed at the back of a glass screen. The glass should be as thin as possible, having a frosted or opaque surface to the audience. Certain mechanical arrangements of shape and reflector can be used according as the flat or raised surface of objects is required for projection. The cost of such an instrument would be very small apart from the ordinary lantern to which it is fixed. He has found the instrument most useful in the field of numismatics and geology.

Systematic Recording of Captures.

Mr. F. Balfour Browne (Belfast Naturalists' Field Club) opened a discussion on the following motion: 'That a Committee of Biologists be formed to recommend the adoption of a Definite System on which collectors should record their captures.' He said that his aim was to make the work of the collector more capable of assimilation by those who study distribution in the British Islands. He pointed out that in a great number of cases the collector publishes his list of captures, only vaguely indicating the limits of the district he has worked, such titles as 'Butterflies from the neighbourhood of . . .' or 'Beetles in the district surrounding . . .' being common.

If all naturalists would adopt a uniform system of recording the results of their collecting a great deal of trouble would be saved to the student of distribution.

Several attempts have already been made to organise such a system. H. C. Watson, in the 'Cybele Britannica,' inaugurated the 'county and vice-county system,' recording the distribution of plants according to their occurrence in the various counties of England and Scotland, but the larger counties he divided up into two or more vice-counties, with the object of making all his areas more or less equal. He also gave a number to each division.

C. C. Babington applied the same system to Ireland, continuing Watson's numbering, so that he commenced with 113 and made altogether 37 divisions. McNab slightly modified Babington's divisions, and renumbered them, commencing with 1. The Conchological Society of Great Britain and Ireland has officially adopted the county and vice-county system, accepting Watson's divisions (and numbering?) for England and Scotland, but taking McNab's modifications for Ireland, and renumbering the Irish divisions, commencing with 113 but not adopting the numbering of Babington.

Praeger in 1896 reviewed the Irish subdivisions and again made some alterations, and once more renumbered them, and his emendations have been almost universally accepted by the younger generation of Irish naturalists. In Scotland there appear to be two factions, one of which adopts Watson's system, while the other divides the country up into 'faunal areas,' the boundaries of which are those of the main drainage areas.

There are, therefore, several systems at present in use, and Mr. Balfour Browne said that it was with a view to bringing them into line that he suggested that a strong committee of biologists should be formed to recommend a definite system, after consulting those who have adopted any of the methods at present in vogue. Such a committee would carry weight with all the local societies, and no doubt the editors of the numerous natural history publications would also pay regard to any recommendation the Committee might make.

Mr. P. Ewing (Glasgow Natural History Society) said that the subject was a large and complicated one, of the peculiarities of which he had gained some experience while working on the Glasgow catalogue of native plants, into which the result of fifteen years' personal work had been incorporated, the area covered being the Watsonian vice-counties forming the West of Scotland. Speaking for that district many divisional systems had been in use and had been discarded for various reasons. Harvie-Brown's naturalists' map, while satisfactory doubtless for avifaunal requirements, was not so well adapted for working the flora, the divisions being too large. Division by squares was also open to objections, as in that case you were dealing with imaginary lines, and one could never tell on which side of the line he was working in mountainous country. Since the last visit of the British Association to Glasgow in 1901 a great stimulus had been given to the work of recording species. The plan followed had been to take the Clyde drainage area as a basis and to note localities, plant associations, &c. This had stood the test of time much better than many of the more artificial systems. At least one can always tell on which side of a stream or watershed one is, and the localisation is definite enough for scientific purposes and not sufficiently clear to aid the extermination of our rarer species. 'In my own work I always saw the plant myself, and when in doubt had the opinion of an expert on the plant before passing it, and from what I have seen I am convinced that nothing short of this is of any value. No doubt this method involves an enormous amount of work which cannot well be subdivided, but correlation from scientific magazines, the transactions of scientific societies, &c., I found could not in all cases be trusted. So far as Scotland is concerned, flowering plants, mosses, hepatics, and fungi have been well recorded, and many doubtful species re-recorded in recent years, so that there is a large body of trustworthy information ready at hand to begin operations upon.'

Mr. T. Sheppard (Yorkshire Naturalists' Union) said that in his opinion the present Watsonian division into vice-counties seemed to meet most requirements, and as it was already in use pretty generally it seemed to be hardly worth while to alter it, particularly as any alteration would in the future cause confusion. With regard to editors of publications it was, of course, possible to publish lists of daisies and buttercups or anything else sent in, but he thought that nowadays a fair amount of discretion was used in publishing lists, and so far as possible the necessary information relating to contributions, &c., is given.

Professor P. F. Kendall said that while recognising the importance of uniformity he feared that it could not be secured unless some inducements were held out to observers to conform to any scheme either by reward or punishment. The strongest inducement would be to offer a good map, and if the speaker were engaged upon a distributional problem he should certainly employ such a map as that of Scotland, exhibited by Mr. Balfour Browne.

Mr. Wilfrid Mark Webb (Selborne Society) said that the difficulty of the task ought not to be considered, and that the method chosen should be that which allowed of generalisation being most easily made. Maps showing the boundaries of the river valleys would be most useful.

Mr. Whitaker (Croydon N. H. and Scientific Society) mentioned that county boundaries meant nothing from the zoological point of view.

Mr. Harold Wager (Leeds Naturalists' Club and Scientific Association) also spoke.

Mr. Balfour Browne in his reply said the system he advocated was meant to be arbitrary. The question arose as to what procedure could be taken if the Conference passed the motion, as the Conference of Delegates apparently had no power to apply to the Committee of Recommendations for the appointment of a special committee.

Professor W. W. Watts (Caradoc and Severn Valley Field Club and Birmingham N. H. and Philosophical Society) thereupon moved as an amendment: 'That the Conference of Delegates approves of the proposal of Mr. F. Balfour Browne, that a committee of biologists be formed to recommend the adoption of a definite system on which collectors should record their captures; and desires its representatives to support before the Committee of Recommendations a proposal from Sections D and K for the appointment of a committee to carry out the suggestion.' This was seconded by Mr. W. Whitaker.

Mr. F. Balfour Browne accepted the amendment, which was passed, and undertook to bring the matter without delay before Sections D and K with a view to nominating the committee.

SECOND MEETING, *September* 6.

In the absence of the Chairman through indisposition, the meeting was presided over by Professor P. F. Kendall (Vice-Chairman).

Professor Kendall, in calling upon Mr. T. R. Wilton (Liverpool Engineering Society), laid emphasis on the far-reaching effects brought about through the revived use of the roads upon the country and the people in their neighbourhood.

The Adaptation of Roads to Fast and Heavy Motor Traffic. By T. R. WILTON, *M.A., Assoc.M.Inst.C.E.*

In bringing forward for discussion the desirability of a further investigation of road conditions I feel that the matter is one of which a great deal has been heard and about which much discussion has already taken place. Nevertheless, it is a matter of which a final solution can never be found, as modifications in traffic must take place as time goes on. It will perhaps be better first to differentiate between the various kinds of traffic which use the roads at the present time, and for this purpose the following rough division into classes may be made: (1) Light and fast horse-drawn vehicles; (2) Heavy horse-drawn vehicles; (3) Light and fast motor vehicles and cycles; (4) Heavy fast motor-vehicles; (5) Heavy slow motor-vehicles, including traction engines.

The varied requirements of these different classes of traffic are somewhat diverse, and may be summarised briefly as follows :—

1. Light horse-drawn vehicles require a smooth and easy-running surface for the wheels, together with reasonably good foothold for the horse and easy gradients, but great strength of road to withstand heavy wheel-pressures without deformation is unnecessary.

2. Heavy horse-drawn vehicles require, in addition to a smooth-running surface for the wheels, considerable strength of road to withstand heavy wheel-pressure and the action of the horses' shoes, which tend to break up the road.

3. Light and fast motor vehicles and cycles require a smooth surface devoid of mud, and one which will not become greasy in any weather or unreasonably

dusty in dry weather, and preferably a level, straight road; but if the road must have curves or gradients, large radius curves and easy gradients.

4. Heavy and fast motor-vehicles require a similar surface, provided it gives sufficient adhesion on inclines; also easy curves and gradients and great strength to withstand the heavy wheel-pressures.

5. Very heavy slow motor-vehicles and traction-engines require very great road strength, otherwise the deformation of the road in bad weather may be so great that not only is the road seriously damaged, but the vehicle itself is 'stalled,' the action of the wheels in some cases being so great that on bad roads the vehicle digs a species of pit through the action of the wheels rotating in one place in their endeavour to force the vehicle along. This class of traffic also requires bridges which are abnormally strong.

Looked at from the point of view of the country at large, two interests are very seriously involved. The first is that of the general commercial, manufacturing, and agricultural community, and of the carriers who desire cheap and quick transport of goods; the second is that of the general community living near the roads whose houses and land may be depreciated in value by the dust and noise of traffic, and who, moreover, are taxed for the maintenance of the roads of which the cost of upkeep rises as the quantity of motor traffic increases.

Many methods of adapting the roads to motor traffic have been tried—some in the nature of palliatives and some in the nature of radical changes—and a great number of experiments and observations have been made to determine the effects of these various methods on resistance to traction, wear of road surfaces, and the effect of dust-proofing or dust-laying materials, both as regards the road itself and the effect of these materials on the surrounding land.

Despite this, a very large amount remains to be done, and I suggest that it is desirable to obtain further information on the following points:—

1. The determination of what may be called the economical compromise gradient for various districts, that is, the gradient which is the best compromise between a perfectly level road requiring considerable alteration of road surface, very expensive to carry out, and a road following the natural contours of the ground, and consequently often forming very steep gradients expensive in horse-flesh or motor power.

2. The tractive force necessary on various gradients with various types of road surface and conditions of weather.

3. The advantage of various types of surfaces in resisting destruction by the wheels of motors, in giving adhesion, and in preventing side-slip, combined with tests of the quality of foothold that they provide for horses.

4. The maximum cross-gradient that roads of various types may have without becoming unsuitable for motor traffic. A perfectly flat road would be best for motor traffic, but such a road devoid of cross-fall would not drain in wet weather, and would probably get in bad condition, even if waterproofed by tar or asphaltic dressings.

5. The effect of various dust-laying materials on the trees and herbage adjoining the road and on the feet of horses using the road.

6. The desirability of strengthening or rebuilding the older road bridges which are now not available for very heavy traffic, in order that they may all be capable of carrying heavy tractors of a fixed standard axle-weight.

I also suggest that it is desirable to investigate the advantages of forming motor-traffic roads which would connect all towns and large villages and should intersect the country, so that no place might be more than a few miles from one of these roads, except in districts where obviously traffic would not justify this expenditure.

Motor-traffic roads should be graded, aligned, and super-elevated at curves with as much skill as is applied to the location and construction of a railway, and it is desirable to inquire whether it would be possible to adapt the ordinary roads to form these motor-traffic roads.

So long ago as November 7, 1883, Mr. Alfred Holt, M.Inst.C.E., the well-known Liverpool shipowner, was explaining and advocating his Lancashire plateway scheme before the Liverpool Engineering Society. This plateway was

a species of railway in which the rails furnished a flat surface provided with a flange so that either ordinary carts and waggons or railway trucks could run on it and be hauled by ordinary railway-engines.

Before the same Society last February, Mr. John Alexander Brodie, the City Engineer of Liverpool, advocated the general principle of the plateway, if constructed in a manner suitable to modern requirements, giving as advantages of a modified plateway the following: (1) Greatest economy in construction; (2) Great economy in haulage; (3) Absence of terminal charges; (4) Suitability for all classes of vehicles at present used for heavy traffic; and (5) The simplest possible arrangements for connecting up to mill, manufactory, or ship.

I suggest that a motor-traffic road should consist essentially of eight steel or iron 'runways' (to use a term applied to the longitudinal stone tracks used in some towns), each of sufficient breadth to ensure that all vehicles could keep their wheels on these, the runways thus forming four definite tracks as on a railway, and the intermediate part of the road being a dust-proof pavement, such as asphaltic macadam or macadam tar-treated, which would give foothold for horses and at the same time be sufficiently strong to bear the load of a vehicle occasionally turning out to pass another vehicle. In order to secure the proper working of traffic on this road it would be necessary to confine slow vehicles to two of the tracks and fast vehicles to the other two, and only to allow slow vehicles to cross the fast tracks at given points, such as side road turnings, and only to turn out into the fast tracks in order to pass slower traffic when there was ample distance from any fast traffic coming along.

Such runways would enable vehicles to be hauled with less than half the frictional resistance of that which even good roads offer, and would give a perfectly even surface similar in smoothness to a railway line. Consequently, not only would economy be effected in the power required for haulage, but the wear and tear of horse-flesh and of motors and other vehicles would be enormously lessened, and it would be possible to do away with the expense of pneumatic or rubber tyres, save where these were required to ensure absolute noiselessness in pleasure vehicles. Ordinary farm waggons, by a small alteration, might be made capable of being drawn on this runway in trains hauled by motors. As an outline type of motor-traffic road the foregoing may serve as a basis of discussion or investigation. Whether the construction of such a type of road would be beneficial to the country generally from the financial aspect requires consideration. I venture to think that it would be. But if such motor-traffic roads were advantageous, the following points would need investigation:—

1. The limits of wheel-gauge desirable, *i.e.*, as to the maximum and minimum gauge which a track should be constructed to suit. The nearer these were to coincidence, the less the cost of track construction would be.

2. The cross-gradient and super-elevation at curves and the minimum radius of curves.

3. The allowable wheel-pressures and allowable dimensions and types of wheel and tyre.

4. The loading gauge of vehicles and clearances between passing vehicles of fast and slow traffic.

5. The limiting velocities of fast and slow traffic.

6. The type of metal most suitable for the runways and the most suitable form of construction of the road.

The discussion on this Paper was opened by Professor Kendall, who was followed by Mr. William Watts (Geological and Mining Society of Manchester), who, speaking of the district around Wilmslow and Alderley Edge, Cheshire, said it is not safe for a lady or gentleman neatly dressed to travel on the main roads after a spell of fine weather for fear of getting their clothes covered with dust raised by the motors so frequently passing that way, whilst on muddy roads one runs the risk of getting splashed with dirty water settled in ruts, as some of the drivers pay no regard to the comfort of the pedestrians on the footpaths. The hedges and small trees are covered with dust, and doubtless their growth is stunted in consequence of the pores in the leaves getting choked with it; and for some distance on both sides of the roads the herbage, cereal, and root crops are damaged, and the land is much reduced in value and will not let for the building

of a better class of houses. He was recently informed that a farmer pasturing cows in a field bordering on the main road lost three of them by death in a very short time, all apparently from the same cause. When the last one died a veterinary surgeon was called in, and on opening the cow he found a hard ball of dust in its stomach, which he declared to be the cause of death, as there was no trace of disease in the animal. This is an extreme case no doubt, but it indicates to what extent motor dust is injurious. Motors are also a nuisance and a danger in passing through villages, especially to the shop-keeping class, and the speed-limit should be much reduced. He did not agree with the reader of the Paper that roads should be specially provided for this class of pleasure traffic. All classes of society should have equal right to the use of public roads for vehicular traffic of every kind, and the rates of the district should not be drawn upon for the exclusive use of a privileged class. In some villages the rates are considerably drawn upon for road watering to lay the dust created by the passing motors, and in some instances the surface of the roads is being formed of material not suited to bear heavy loads. No surveyor who understands his profession will make his roads with too much camber.

Mr. J. A. Longden (Institution of Mining Engineers), referring to the treatment of roads, said that tar macadam had come to stop, and that spraying was only a temporary measure. He noticed at Dunkeld a few years ago that tar had been sprayed on the narrow streets, and as it was wet weather, when any vehicle came down the street the tar was splashed right across the footpath, ruining everybody's clothes. Spraying has no doubt been improved since then, but the fact remains that spraying is a mistake unless you have a tar macadam road first, and then a little tar and dust to renew the surface may be beneficial, but he thought that the less spraying there is the better. The dust question in Derbyshire, where the roads are chiefly of limestone, is most serious. Speaking of a conversation he had recently with Sir George Gibb, the Chairman of the Road Board, and Colonel Crompton, the consulting engineer, so far as he could gather they were both of them distinctly in favour of tar macadam. He was afraid the 500,000*l*. per annum which they have at their disposal will not go very far in putting the roads of Great Britain into good condition, and we shall probably find that this sum, which is derived principally from the use of motor-cars, will be spent in improving the main roads which are used by motor-cars most frequently.

Mr. J. H. Priestley (Bristol Naturalists' Society) said that a good many plants were not harmed by dust, as the hairs on their leaves protected them. He had also been told by farmers that the ravages of the turnip flea beetle were largely minimised by the dust which drifted over the fields from neighbouring roads. Some tars, or tar-like materials, should not be put down, as they spoilt plant life by vaporisation. An insoluble material should be used. It was desirable that naturalists' societies should show a keen interest in the question of improving the roads, so that vegetation and animal life did not suffer either from the preparations applied to the road or from the traffic using the road, and not simply take up a conservative attitude and deprecate the inevitable use of motor-driven vehicles in country districts.

Professor W. W. Watts (Birmingham N. H. and Philosophical Society) said that with the new conditions of road traffic we must revise our ideas. The unskilfully made road, with occasional watering to lay the dust, is now no longer feasible. Again, the road trouble is mainly due to the difficulty of accommodating two classes of traffic, wheel-traction and hoof-traction. The best types of surface for the former were not the best for the latter form of traction. The dust nuisance is so great an evil that it must be combated and abolished. Something has been done already, for forty years ago roads were almost as dusty under horse traffic as they now are under motor traffic, and the same observation applied to railways before proper ballast was used. Among the things wanted are (1) proper foundations like those built under the Roman roads; (2) greatly diminished camber to distribute the traffic, to avoid skidding, and to diminish water erosion; (3) waterproofing of the surface and a proper binding of the constituents to check grinding and shifting of these materials; (4) the removal of dust and mud as formed instead of replacing it as 'binding' to renew the same vicious cycle.

Principal Griffiths drew attention in the revised use of the roads to the offence to the eyes of the motor-trade advertisements, to which the firms say they are

opposed, but to which they are driven by competition. The evil should be controlled by legislation. As to the injurious dust from tarred roads, this was due to the use of bad materials. Pure tar had not the same faults.

Mr. W. P. D. Stebbing mentioned as one of the results of spraying that fish were said to be poisoned by water draining from roads so treated into neighbouring streams. To account for some of the present road troubles he drew attention to their almost utter neglect since the introduction of railways. Up to that date continuous improvements were being made, and coach traffic was at such a pitch of perfection that with relays of horses speeds of ten to twelve miles an hour were kept up for hundreds of miles.

Mr. A. W. Oke (Brighton and Hove N. H. and Philosophical Society) spoke strongly as to the great injury that was being done by fast motor-traffic to local natural history societies and to all those to whom a quiet roadside appealed. He thought that all roadside advertisements should be taxed.

Mr. Bryan Corcoran also spoke.

Mr. T. R. Wilton, in his reply, sympathised with Professor Kendall in his views as to the 'uglifying' of the country. As a foot passenger he objected to motors, but as an engineer swift motor-traffic appealed strongly to him. He considered that Mr. Watts' statement about the mortality amongst cattle pastured on land near roads carrying a great amount of motor traffic emphasised the necessity of getting dustless roads. The remarks of Mr. J. H. Priestley about the destruction of plants by certain dust-laying materials used on the road showed the necessity of only using suitable substances and of investigating their effect before adopting them. Professor Watts had put the case for road reconstruction very clearly in urging the necessity for properly made roads and in pointing out the wisdom of large capital expenditure to avoid the heavy annual charges necessary on many of the present roads, and the folly of the methods of road repair adopted in many districts. Principal Griffiths also had emphasised the necessity of only using proper materials on roads in order to avoid damage to adjacent lands, and in describing motors as a blessing in disguise, which would lead to the roads being made thoroughly dustless, he had expressed an opinion which should have a great effect in getting local bodies to take a broadminded view of the matter. Professor Watts had dealt with and condemned the high camber of roads, but it was necessary to emphasise the fact that high camber was extremely bad, and that a road for even ordinary traffic should be as flat as was consistent with drainage, and in the case of motor traffic that a road with slight cross-gradient was essential.

Discussion on the Ordnance and Geological Survey Maps and the enhanced Prices.

Professor Kendall, as Vice-Chairman, introduced a discussion on the above matters. In his remarks he said that on notification of this recent prohibitive increase of price the Board of Agriculture and Fisheries were memorialised, but to no effect, although it was pointed out that the intention of the Geological Survey was by such policy defeated. As to the Ordnance Survey he inveighed against the policy followed in dealing with the whole of the country, which showed inconsistency in both publication, paper, and in the drawing of the maps. Such an important matter as contouring was not uniform, and in the 6-inch maps some changes made in the different editions were not justifiable.

Professor W. W. Watts confirmed what Professor Kendall had said as to the result of the appeal to the Government. As in any case the cost of the Geological Survey had to be borne, the cost of the addition of their lines to the uncoloured maps could be very little—the only point is the addition of hand-colouring each map, and the expense of this could be easily got back. The matter should not be allowed to rest. It was one that especially affected local societies. Professor Watts also mentioned that the Ordnance Survey allowed reproduction of their maps for schools at cheap rates, but this unfortunately was not general and did not include the colour-printed maps.

Mr. H. Kidner (Hertfordshire N. H. Society) suggested that concerted action should be taken. He asked if a requisition could not be sent up from the

Conference of Delegates to the Council of the British Association asking them to take some action in the matter.

Mr. A. W. Oke thought that the Chairman had brought forward a matter of great importance. If Government would not reconsider their decision could not the local societies memorialise their members of Parliament?

After further discussion, Professor Watts said that the Corresponding Societies Committee might consider the advisability of the local societies bringing pressure to bear on their members of Parliament, and if so the societies should report to the Committee the result of their action.

It was eventually proposed by Mr. Kidner, seconded, and carried unanimously: 'That the Corresponding Societies Committee consider the advisability of inviting the societies represented at the Conference of Delegates to communicate with the Treasury and with their members of Parliament, with a view to reverting to the old prices of the Geological Survey maps.'

The meeting then adjourned, after passing a hearty vote of thanks to Dr. Tempest Anderson and Professor Kendall for presiding.

The Corresponding Societies of the British Association for 1910–1911.

Affiliated Societies.

Full Title and Date of Foundation	Headquarters or Name and Address of Secretary	No. of Members	Entrance Fee	Annual Subscription	Title and Frequency of Issue of Publications
Andersonian Naturalists' Society, 1885	Technical College, Glasgow. R. Barnett Johnstone and George Lunam	320	None	2s. 6d.	Annals, occasionally.
Ashmolean Natural History Society of Oxfordshire, 1828	Miss A. L. Stone, 2 St. Margaret's Road, Oxford	302	None	5s.	Report, annually.
Belfast Natural History and Philosophical Society, 1821	Museum, College Square. R. M. Young, M.R.I.A.	250	None	1l. 1s.	Report and Proceedings, annually.
Belfast Naturalists' Field Club, 1863	Museum, College Square. A. W. Stelfox and Miss Jean Agnew	335	5s.	5s.	Report and Proceedings, annually.
Berwickshire Naturalists' Club, 1831	Rev. J. J. M. L. Aiken, B.D., Manse of Ayton, Berwickshire	400	10s.	8s. 6d.	History of the Berwickshire Naturalists' Club, annually.
Birmingham and Midland Institute Scientific Society, 1859	Alfred Cresswell, Birmingham and Midland Institute, Paradise Street, Birmingham	137	None	10s. 6d. and 5s.	Records of Meteorological Observations, annually.
Birmingham Natural History and Philosophical Society, 1858	Avebury House, Newhall Street, Birmingham. P. E. Martineau and Herbert Stone, F.L.S.	197	None	1l. 1s.	Proceedings, occasionally.
Bournemouth Natural Science Society, 1903	Dr. J. R. L. Dixon, Sherbrook, Christchurch Road, Bournemouth	300	None	10s.	Report and Proceedings, annually.
Brighton and Hove Natural History and Philosophical Society, 1854	J. Colbatch Clark, 9 Marlborough Place, Brighton	176	None	10s.	Report, annually.
Bristol Naturalists' Society, 1862	J. H. Priestley, B.Sc., The University, Bristol	149	5s.	10s. and 5s.	Proceedings, annually.
British Mycological Society, 1896	Carleton Rea, 34 Foregate Street, Worcester	92	None	10s.	Transactions, annually.
Buchan Club, 1887	J. F. Tocher, B.Sc., 5 Chapel Street, Peterhead	180	5s.	5s.	Transactions, annually.
Burton-on-Trent Natural History and Archæological Society, 1876	H. Lloyd Hind, B.Sc., Ravenscliff, Stapenhill, Burton-on-Trent	250	None	5s.	Report, annually; Transactions, occasionally.
Canada Royal Astronomical Society of, 1884	Canadian Institute Building, Toronto. J. R. Collins	450	None	2 dollars	Journal, bi-monthly.
Caradoc and Severn Valley Field Club, 1893	H. E. Forrest, 37 Castle Street, Shrewsbury	208	5s.	5s.	Transactions and Record of Bare Facts, annually.
Cardiff Naturalists' Society, 1867	W. Gilbert Scott, 25 Duke Street, Cardiff	480	None	12s. 6d.	Transactions, annually.
Chester Society of Natural Science, Literature, and Art, 1871	Grosvenor Museum, Chester. F. Simpson	1,025	None	5s. and 2s. 6d.	Report, annually; Proceedings, occasionally
Cornwall, Royal Geological Society of, 1814	The Museum, Public Buildings, Penzance. John B. Cornish	82	None	1l. 1s.	Transactions, annually.
Cornwall, Royal Institution of, 1818	George Penrose, F.L.S., County Museum, Truro	190	None	1l. 1s.	Journal, annually.
Cornwall, Royal Polytechnic Society, 1833	E. W. Newton, Camborne, Cornwall	400	None	10s. upwards	Report, annually.
Croydon Natural History and Scientific Society, 1870	Public Hall, Croydon. G. W. Moore	135	None	10s., 5s., and 2s. 6d.	Proceedings and Transactions, annually.
Dorset Natural History and Antiquarian Field Club, 1875	Rev. Herbert Pentin, M.A., M.R.A.S., Milton Abbey Vicarage, Dorset	400	10s.	10s.	Proceedings, annually.
Dublin Naturalists' Field Club, 1885	J. Stafford Johnson, B.A., 27 Northumberland Road, Dublin	126	Memb. 5s.; Assoc. none	Members 5s.; Associates 2s. 6d.	'Irish Naturalist,' monthly; Report, annually.

Dumfriesshire and Galloway Natural History and Antiquarian Society, 1862	S. Arnott, Sunnymead, Dumfries	260	None	5s.	Transactions and Proceedings, annually
East Kent Scientific and Natural History Society, 1857	A. Lander, 17 High Street, Canterbury	84	None	10s. and 5s.	Transactions, annually.
Eastbourne Natural History, Scientific, and Literary Society, 1867	Henry Sparks, Villa Ruhe, 5 St. Leonard's Road, Eastbourne	74	2s. 6d.	7s. 6d.	Transactions, biennially.
Edinburgh Field Naturalists' and Microscopical Society, 1869	Allan A. Pinkerton, 59 Frederick Street, Edinburgh	209	5s.	5s.	Transactions, annually.
Edinburgh Geological Society, 1834	India Buildings, Edinburgh. David Gloag	242	10s. 6d.	12s. 6d.	Transactions, annually.
Elgin and Morayshire Literary and Scientific Association, 1836	Norris Mackay, W.S., Elgin	102	None	5s.	Transactions, occasionally.
Essex Field Club, 1880	Essex Museum of Natural History, Romford Road, Stratford. W. Cole and B. G. Cole	300	None	15s.	'Essex Naturalist,' quarterly; 'Year-book,' annually; 'Special Memoirs,' &c., occasionally.
Glasgow, Geological Society of, 1858	Peter Macnair, F.R.S.E., 207 Bath Street, Glasgow	300	None	10s.	Transactions and Proceedings, annually.
Glasgow, Natural History Society of, 1851	Alex. Ross, 409 Great Western Road, Glasgow	245	None	7s. 6d.	'Glasgow Naturalist,' quarterly.
Glasgow, Royal Philosophical Society of, 1802	Prof. Peter Bennett, 207 Bath Street, Glasgow	1,000	1l. 1s.	1l. 1s.	Proceedings, annually.
Hampshire Field Club and Archæological Society, 1885	W. Dale, F.S.A., F.G.S., The Lawn, Archer's Road, Southampton	250	5s.	10s. 6d.	Proceedings, annually.
Hertfordshire Natural History Society and Field Club, 1875	Charles Oldham, F.Z.S., Essex House, Watford, and A. E. Gibbs, F.L.S., St. Albans	155	10s.	10s.	Transactions, yearly.
Holmesdale Natural History Club, 1857	Miss M. C. Crosfield, Undercroft, Reigate	81	None	10s. and 5s.	Proceedings, occasionally.
Hull Geological Society, 1887	J. W. Stather, F.G.S., Newland Park, Hull	65	None	5s.	Transactions, occasionally.
Hull Scientific and Field Naturalists' Club, 1886	T. Stainforth, The Museum, Hull	132	None	5s.	Transactions, annually.
Institution of Mining Engineers, 1889	Percy Strzelecki, 39 Victoria Street, London, S.W.	3,300	None	None	Transactions, monthly.
Ireland, Statistical and Social Inquiry Society of, 1847	W. Lawson, Dr. N. M. Falkiner, and Herbert Wood, 35 Molesworth Street, Dublin	80	None	1l.	Journal, annually.
Leeds Geological Association, 1873	E. Hawkesworth, Crossgates, Leeds	120	None	5s.	Transactions, occasionally.
Leicester Literary and Philosophical Society, 1835	Corporation Museum. W. A. Evans, 24 Fosse Road South, Leicester	350 Membs. & Associates	None	Members 1l. 1s.; Associates 10s. 6d.	Transactions, half-yearly.
Lincolnshire Naturalists' Union, 1893	Arthur Smith, F.L.S., City and County Museum, Lincoln	110	None	5s.	Transactions, annually.
Liverpool Biological Society, 1886	J. A. Clubb, D.Sc., Free Public Museum, Liverpool	101	10s. 6d. and 2s. 6d.	1l. 1s. and 10s. 6d.	Proceedings and Transactions, annually.
Liverpool Botanical Society, 1906	A. A. Dallman, F.C.S., 111 Penny Lane, Wavertree, Liverpool	177	None	5s.	Proceedings, annually; Transactions, occasionally.
Liverpool Engineering Society, 1875	T. R. Wilton, M.A., 1 Crosshall Street, Liverpool	538	None	1l. 1s. and 10s. 6d.	Transactions and Report, annually.
Liverpool Geographical Society, 1891	Capt. E. C. Dubois Phillips, R.N., 14 Hargreave's Buildings, Liverpool	650	None	Members 1l. 1s.; Associates 10s. 6d.	Transactions and Report, annually.
Liverpool Geological Society, 1858	Royal Institution. W. A. Whitehead, B.Sc.	66	None	1l. 1s. and 10s. 6d.	Proceedings, annually.
London: Quekett Microscopical Club, 1865	W. B. Stokes, 4 Winn Road, Lee, S.E.	455	None	10s.	Journal, half-yearly.
London: Selborne Society, 1885	42 Bloomsbury Square, W.C. W. M. Webb, F.L.S.	2,700	None	5s.	'Selborne Magazine,' monthly.
Man, Isle of, Natural History and Antiquarian Society, 1879	P. M. C. Kermode, Claghbane, Ramsey, Isle of Man	198	2s. 6d.	7s. 6d. and 5s.	Proceedings, twice a year; Transactions, occasionally.
Manchester Geographical Society, 1884	J. Howard Reed, 16 St. Mary's Parsonage, Manchester	720	None	Members 1l. 1s.; Associates 10s. 6d.	Journal, quarterly.

Affiliated Societies—continued.

Full Title and Date of Foundation	Headquarters or Name and Address of Secretary	No. of Members	Entrance Fee	Annual Subscription	Title and Frequency of Issue of Publications
Manchester Geological and Mining Society, 1838	5 John Dalton Street, Manchester. Sydney A. Smith	300	None	2*l.* 2*s.*, 1*l.* 5*s.*, and 1*l.*	Transactions of Inst. of Mining Engineers, monthly.
Manchester Microscopical Society, 1880	Frederick Dishley, 14 Westwood Street, Moss Side, Manchester	190	5*s.*	6*s.*	Transactions and Report, annually.
Manchester Statistical Society, 1833	Herbert Heape and F. Vernon Hansford, 3 York Street, Manchester	169	10*s.* 6*d.*	10*s.* 6*d.*	Transactions, annually.
Marlborough College Natural History Society, 1864	E. Meyrick, F.R.S., Marlborough College	300	1*s.* 6*d.*	3*s.* and 5*s.*	Report, annually.
Midland Counties Institution of Engineers, 1871	G. Alfred Lewis, M.A., Albert Street, Derby	396 Membs.,	1*l.* 1*s.*	Members 42*s.*;	Transactions of Institution of Mining Engineers, monthly.
		Associates & Students	None	Associates and Students 20*s.*	
Midland Institute of Mining, Civil, and Mechanical Engineers, 1869	L. T. O'Shea, The University, Sheffield	306	None	1*l.* 10*s.*	Transactions of Inst. of Mining Engineers, monthly.
Norfolk and Norwich Naturalists' Society, 1869	W. A. Nicholson, 61 Surrey Street, Norwich	279	None	6*s.*	Transactions, annually.
North of England Institute of Mining and Mechanical Engineers, 1852	Neville Hall, Newcastle-upon-Tyne	1,358	None	25*s.* and 42*s.*	Transactions of Inst. of Mining Engineers, monthly.
North Staffordshire Field Club, 1865	W. Wells Bladen, Stone, Staffs	596	5*s.*	5*s.*	Report and Transactions, annually.
Northamptonshire Natural History Society and Field Club, 1876	H. N. Dixon, M.A., 17 St. Matthew's Parade, Northampton	210	None	10*s.*	Journal, quarterly.
Northumberland, Durham, and Newcastle-upon-Tyne, Natural History Society of, 1829	Hancock Museum, Newcastle-on-Tyne. N. H. Martin, F.L.S., and C. E. Robson	410	None	21*s.*	Transactions, annually.
Nottingham Naturalists' Society, 1852	Prof. J. W. Carr, M.A., University College, Nottingham	195	2*s.* 6*d.*	5*s.*	Report and Transactions, annually.
Paisley Philosophical Institution, 1808	J. Gardner, 3 County Place, Paisley	546	5*s.*	7*s.* 6*d.*	Report and Meteorological Observations, annually.
Perthshire Society of Natural Science, 1867	Tay Street, Perth. S. T. Ellison	382	2*s.* 6*d.*	5*s.* 6*d.*	Transactions and Proceedings, annually.
Rochdale Literary and Scientific Society, 1878	J. Reginald Ashworth, D.Sc., 105 Freehold Street, Rochdale	234	None	6*s.*	Transactions, biennially.
Rochester Naturalists' Club, 1878	John Hepworth, Linden House, Rochester	166	None	5*s.*	'Rochester Naturalist,' quarterly.
Somersetshire Archæological and Natural History Society, 1849	The Castle, Taunton. Rev. F. W. Weaver, Rev. E. H. B. Harbin, and C. Tite	810	10*s.* 6*d.*	10*s.* 6*d.*	Proceedings, annually.
South Africa, Royal Society of, 1908	G. M. Clark, South African Museum, Cape Town	207	None	2*l.*	Transactions, occasionally.
South-Eastern Union of Scientific Societies, 1896	W. Martin, LL.D., 2 Garden Court, Temple, E.C.	53 Societies	None	Minimum 5*s.*	'South-Eastern Naturalist,' annually.
Southport Literary and Philosophical Society	A. H. Garstang, 120 Roe Lane, Southport	130	None	7*s.* 6*d.*	Proceedings, occasionally.
South Staffordshire and Warwickshire Institute of Mining Engineers, 1867	G. D. Smith, 3 Newhall Street, Birmingham	170	1*l.* 1*s.* and 10*s.* 6*d.*	42*s.* and 21*s.*	Transactions of Institution of Mining Engineers, monthly.
Torquay Natural History Society, 1844	Major E. V. Elwes, The Museum, Torquay	177	10*s.* 6*d.*	1*l.* 1*s.*	Journal, annually.

TynesideGeographical Society, 1887	Geographical Institute, St. Mary's Place, Newcastle-on-Tyne. Herbert Shaw, B.A., F.R.G.S.	1,000	None	10*s.* and 5*s.*	Journal, annually.
Vale of Derwent Naturalists' Field Club, 1887	J. E. Patterson, Mossgiel, Rowlands Gill, R.S.O.	140	None	2*s.* 6*d.*	Transactions, occasionally.
Warwickshire Naturalists' and Archæologists' Field Club, 1854	Museum, Warwick. C. West, Cross Cheaping, Coventry	70	2*s.* 6*d.*	5*s.*	Proceedings, annually.
Woolhope Naturalists' Field Club, 1851	Woolhope Club Room, Free Library, Hereford. T. Hutchinson	216	10*s.*	10*s.*	Transactions, occasionally.
Worcestershire Naturalists' Club, 1847	Education Offices, Worcester, F. T. Spackman, F.G.S.	130	10*s.*	5*s.*	Transactions, annually.
Yorkshire Geological Society, 1837	W. Lower Carter and Cosmo Johns, Burngrove, Pitsmoor Road, Sheffield	213	None	13*s.*	Proceedings, annually.
Yorkshire Naturalists' Union, 1861	The Museum, Hull. T. Sheppard, F.G.S.	434 and 4,026 Associates	None	10*s.* 6*d.*	Transactions, annually; 'The Naturalist,' monthly.
Yorkshire Philosophical Society, 1822	Museum, York. Dr. Tempest Anderson and C. E. Elmhirst	700	None	2*l.*	Report, annually.

Associated Societies.

Balham and District Antiquarian and Natural History Society, 1897	A. L. Barron, Clophill, Wallington, Surrey	78	None	5*s.*	Papers, occasionally.
Barrow Naturalists' Field Club and Literary and Scientific Association, 1876	Cambridge Hall, Strand, Barrow. W. L. Page, 5 Cavendish Street	264	None	5*s.* and 2*s.* 6*d.*	Report and Proceedings, annually.
Battersea Field Club, 1894	Public Library, Lavender Hill, Battersea, S.W. Miss L. B. Morris	65	None	3*s.* 6*d.*	——
Bradford Natural History and Microscopical Society, 1875	Fred. Jowett, 2 Vincent Street, Bradford	75	1*s.*	4*s.*	Report, annually.
Bradford Scientific Association, 1875	A. Smith, Springfield, Guiseley, Yorks.	200	None	5*s.* and 2*s.* 6*d.*	Bradford Scientific Journal, quarterly.
Catford and District Natural History Society, 1897	W. H. Griffin, 40 Blythe Vale, Catford, S.E.	80	1*s.*	3*s.*	——
Dover Sciences Society, 1879	Arthur W. Gilham, Holmesdale, Priory Hill, Dover	70	None	6*s.*	Reports, annually; Leaflets occasionally.
Dunfermline Naturalists' Society, 1902	Robert Somerville, B.Sc., 38 Cameron Street, Dunfermline	180	None	3*s.*	——
Ealing Scientific and Microscopical Society, 1877	F. McNeil Rushforth, Coley Lodge, 21 Florence Road, Ealing, W.	189	None	10*s.* and 2*s.* 6*d.*	Report and Transactions, annually.
Grimsby and District Antiquarian and Naturalists' Society, 1896	The Museum, Grimsby. Dr. G. A. Grierson	90	None	4*s.*	——
Halifax Scientific Society, 1874	F. Barker, 11 Hall Street, Halifax	133	None	2*s.* 6*d.*	——
Hampstead Scientific Society, 1899	C. O. Bartrum, B.Sc., and R. W. Wylie, M.A., 12 Heath Mansions, Heath Street, Hampstead, N.W.	301	None	Minimum 5*s.*	Report and Proceedings, annually.
Hastings and St. Leonards Natural History Society, 1893	Corporation Museum, Brassey Institute, Hastings. W. Ruskin Butterfield	520	1*s.*	2*s.* 6*d.*	'Hastings and East Sussex Naturalist,' half-yearly.
Hawick Archæological Society, 1856	W. Murray, 6 Duke Street, Hawick	249	None	2*s.* 6*d*	Transactions, annuall

Associated Societies—continued.

Full Title and Date of Foundation	Headquarters or Name and Address of Secretary	No. of Members	Entrance Fee	Annual Subscription	Title and Frequency of Issue of Publications
Hull Junior Field Naturalists' Society, 1904	A. J. Moore, 9 Brook Street, Hull	53	None	4s.	Proceedings, occasionally.
Inverness Scientific Society and Field Club, 1875	W. J. Watson, Royal Academy, Inverness	197	None	5s.	Transactions, occasionally.
Ipswich and District Field Club, 1903	C. R. Hacon, 107 Rosehill Road, Ipswich	180	None	2s. 6d.	Journal, annually.
Lancashire and Cheshire Entomological Society, 1877	Royal Institution, Liverpool. H. R. Sweeting, M.A.	140	None	5s.	Report and Proceedings annually.
Leeds Naturalists' Club and Scientific Association, 1868	C. H. B. Turner, 37 Sholebroke Place, Leeds	84	None	6s.	Proceedings, occasionally.
Lewisham Antiquarian Society, 1885	J. W. Brookes, Pembroke Lodge, Slaithwaite Road, Lewisham, S.E.	99	None	5s.	Transactions, occasionally.
Liverpool Microscopical Society, 1868	Royal Institution, Liverpool. R. Croston	55	None	10s. 6d.	Report, annually.
Liverpool Science Students' Association, 1881	Royal Institution, Liverpool. H. W. Greenwood	48	2s. 6d.	5s.	—
Llandudno and District Field Club, 1906	R. S. Underwood, Bodnor House, Lloyd Street, Llandudno	120	None	5s.	Proceedings, annually.
London: City of London Entomological and Natural History Society, 1858	The London Institution, Finsbury Circus, E.C. T. H. L. Grosvenor.	79	2s. 6d.	7s. 6d.	Transactions, annually.
London: North London Natural History Society, 1892	R. W. Robbins, Tonah, Falmouth Avenue, Hale End, Chingford	120	2s. 6d.	5s. and 2s. 6d.	Report, annually.
London: South London Entomological and Natural History Society, 1872	Hibernia Chambers, London Bridge, S.E. Stanley Edwards, F.L.S., and H. J. Turner	170	2s. 6d.	7s. 6d.	Proceedings, annually.
Maidstone and Mid-Kent Natural History Society, 1868	Maidstone Museum. A. Barton and J. W. Bridge	109	None	10s. and 5s.	Report, triennially.
Newcastle-upon-Tyne, Literary and Philosophical Society of, 1793	Newcastle-upon-Tyne. Alfred Holmes and Frederick Emley	2,800	None	1l. 1s.	—
Penzance Natural History and Antiquarian Society, 1839	Public Buildings, Penzance. J. B. Cornish	50	None	10s. 6d.	Transactions, occasionally.
Preston Scientific Society, 1893	Lecture Hall, 119A Fishergate, Preston. W. Hy. Heathcote	426	None	5s.	Papers, occasionally.
Scarborough Philosophical and Archæological Society, 1828	The Museum, Scarborough. E. Arnold Wallis	101	None	1l. and 10s.	Report, annually.
School Nature Study Union, 1903	H. E. Turner, 1 Grosvenor Park, Camberwell, S.E.	1,150	None	2s. 6d.	'School Nature Study,' four times a year.
Scottish Microscopical Society, 1888	Philosophical Institution, 4 Queen Street, Edinburgh. Dr. W. G. Aitchison Robertson	75	None	10s. 6d.	Proceedings, biennially.
Southport Society of Natural Science, 1890	G. H. Hibbott, Shaftesbury Buildings, Eastbank Street, Southport	268	None	5s.	Report, annually.
Teign Naturalists' Field Club, 1858	John S. Amery, Druid, Ashburton, Devon	120	None	2s. 6d.	Report, annually.
Tunbridge Wells Natural History and Philosophical Society, 1884	D. Davies, M.B., 8 Lonsdale Gardens, Tunbridge Wells	130	None	10s. 6d. and 5s.	—
Warrington Field Club, 1884	Alf. J. Jolley, 16 Arpley Street, Warrington	54	None	2s.	—
Watford Camera Club, 1902	W. J. Edmonds, 3 The Parade, Watford	60	None	10s. 6d.	—

Catalogue of the more important Papers, especially those referring to Local Scientific Investigations, published by the Corresponding Societies during the year ending May 31, 1910.

*** This Catalogue contains only the titles of papers published in the volumes or parts of the publications of the Corresponding Societies sent to the Secretary of the Committee in accordance with Rule 2.

Section A.—Mathematical and Physical Science.

Anderson, E. M. On the Temperature-Gradients of Deep Bores, with special reference to those of the Balfour Bore, Cameron Bridge, Fifeshire. 'Trans. Edinburgh Geol. Soc.' IX. 167–178. 1909.

Andson, Rev. W. The Weather of 1907. 'Trans. Dumfriesshire and Galloway N. H. A. Soc.' XX. 64–69. 1909.

Banfield, A. C. On a Method of preparing Stereo-photomicrographs. 'Journal Quekett Mic. Club,' X. 459–464. 1909.

Brighton and Hove Natural History and Philosophical Society. Meteorology of Brighton. 'Report Brighton and Hove N. H. Phil. Soc.' 1908–09, 48–49. 1909.

Cadman, Prof. John (N. Staff. Inst. Eng.). The Ignition of Coal-dust by a Naked Light. 'Trans. Inst. Min. Eng.' XXXVIII. 256–258. 1910.

—— (S. Staff. and Warwick Inst. Eng.). Some Experiments to illustrate the Ignition of Coal-dust by means of Electricity. 'Trans. Inst. Min. Eng.' XXXIX. 93–96. 1910.

Campbell-Bayard, F. Report of the Meteorological Committee, 1908. 'Trans. Croydon N. H. Sci. Soc.' 1908–09, 205, and Appendices, 62 pp. 1909.

—— Report of the Meteorological Committee, 1909. 'Trans. Croydon N. H. Sci. Soc.' 1909–10, 3–10, and Appendices, 62 pp. 1910.

Cannon, J. B. The Spectroscopic Binary α Coronæ. 'Journal Roy. Astr. Soc. of Canada,' III. 419–424. 1909.

Caradoc and Severn Valley Field Club. Meteorological Notes. 'Record of Bare Facts,' No. 19, 36–49. 1910.

Chant, C. A. Water Vapour and Oxygen on Mars. 'Journal Roy. Astr. Soc. of Canada,' III. 425–437. 1909.

—— Halley's Comet. 'Journal Roy. Astr. Soc. of Canada,' IV. 104–115. 1910.

Craw, J. H. Account of Rainfall in Berwickshire—year 1907. 'History Berwickshire Nat. Club,' XX. 220. 1909.

—— Account of Temperature at West Foulden—year 1907. 'History Berwickshire Nat. Club,' XX. 221. 1909.

Cresswell, Alfred. Records of Meteorological Observations taken at the Observatory, Edgbaston, 1909. 'Birm. and Mid. Inst. Sci. Soc,' 28 pp. 1910.

De Lury, Ralph E. Convection and Stellar Variation. 'Journal Roy. Astr. Soc. of Canada,' III. 344–355. 1909.

Fox, W. Lloyd, and Edward Kitto. Meteorological and Magnetical Tables and Report for the Year 1909, and Tables of Sea Temperature, with Notes. 'Report Royal Cornwall Poly. Soc.' I. (N.S.), 1–27. (App.) 1910.

Freeland, Dr. Fergus. Presidential Address: Part I. Present Position and Prospects of the Royal Philosophical Society of Glasgow. Part II. Bishop Berkeley and his New Theory of Vision. 'Proc. Glasgow Royal Phil. Soc.' XL. 1–15. 1909.

Gray, James G., and Hugh Higgins. On Reversible Conditions brought about in Magnetised Steel by Alternate Cooling and Warming. 'Proc. Glasgow Royal Phil. Soc.' XL. 113–118. 1909.

Hall-Edwards, John. The X-Rays: a History of their Progress. 'Proc. Birmingham N. H. Phil. Soc.' XII. 13–37. 1910.

Halper, W. E. The System of ε Herculis. 'Journal Roy. Astr. Soc. of Canada,' III. 377–386. 1909.

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Report on the History and Present State of the Theory of Integral Equations. By H. BATEMAN.

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CONTENTS.

1. *Integral Equations of Laplace's Type.*

THE theory of integral equations may be said to have commenced in 1782, when *Laplace*[1] used definite integrals of the type

$$\int e^{xt}\phi(t)dt = f(x) \quad . \quad . \quad . \quad . \quad (1)$$

to solve linear difference and differential equations, for in these investigations he gave a method of determining the unknown function $\phi(t)$, appearing under the sign of integration, when a linear differential equation satisfied by the function $f(x)$ is known. The determination of $\phi(t)$ depends upon the solution of a corresponding linear differential

[1] 'Mémoire sur les approximations des formules qui sont fonctions de très grands nombres,' *Œuvres*, t. 10, p. 235; *Théorie analytique des probabilités* (Paris: 1812).

equation which has been called by Poincaré the *Laplace transformed equation*.

Laplace extended his method to definite integrals of the type

$$\int t^{z-1}\phi(t)dt = g(z) \quad . \quad . \quad . \quad . \quad (2)$$

and made considerable use of the method in his researches on probability.

It will be convenient to call integral equations of the type (1) and (2) *integral equations of Laplace's type.* The term integrals of Laplace's type is sometimes given to integrals of the form

$$\int \cos(xt)\phi(t)dt,$$

but it is more convenient to name these after Fourier.

The integral equation (1) was studied by Abel,[1] who obtained a number of properties of Laplace's transformation. Abel also proposed the problem of solving an integral equation of the first kind, and stated that he had obtained a solution for a general type of equation.[2] The equation (2) was studied as an *integral equation* for determining $\phi(t)$ when $g(t)$ is known *explicitly* by Robert Murphy[3] in 1832–1834. He gave the formula

$$\phi(t) = \text{coeff. of } \frac{1}{z} \text{ in } g(z)t^{-z}$$

and considered the general problem of determining a function $\chi(t)$ for which

$$o = \int_{o}^{1} t^{z-1}\chi(t)dt \quad . \quad . \quad . \quad . \quad (3)$$

when z has the values $1, 2, \ldots n$. The last problem had been treated previously by Jacobi,[4] but not solved completely. It was shown by Liouville[5] that the above equation cannot be satisfied for all positive integral values of z when $\chi(t)$ is a function which only changes sign a finite number of times. This result is of importance in settling the question of the *uniqueness* of the solution of an equation of Laplace's type. The result was extended by Lerch,[6] in 1892, to the case in which $\chi(t)$ is continuous, and has been extended to other sequences of values of z and other types of function $\chi(t)$ by a number of subsequent writers.[7] It has been shown by Kluyver and Nielsen that equations of type (2) are of great importance in expansions in series of inverse factorials.

The integral equation

$$f(x) = \int^{\infty} t^{x}\phi(t)dt \quad . \quad . \quad . \quad . \quad (4)$$

[1] *Œuvres*, t. 2, p. 67. [2] *Ibid.*, t. 1, p. 11.
[3] *Camb. Phil. Trans.*, vol. iv., 1833, pp. 353–408.
[4] *Crelle's Journal*, vol. i., p. 301 (1826). [5] *Liouville's Journal*, t. 2, p. 1, 1837.
[6] *Acta Math.*, 1903, p. 339.
[7] Stieltjes (1893), *Correspondance de Hermite et Stieltjes*; Landau, *Rend. Palermo*, 1908; C. N. Moore, *Bull. Amer. Math. Soc.*, 1908; W. H. Young, 1910, *Mess. Math.*, vol. lx.

was used by Riemann[1] in some researches on the law of distribution of prime numbers. He gave the inversion formula

$$\phi(t) = \frac{1}{2\pi i}\int_{a-\infty i}^{a+\infty i} t^{-x-1} f(x)dx.$$

This inversion formula has been studied very thoroughly by Mellin,[2] and is of considerable importance in the theory of the Gamma and Hypergeometric functions. The solution of the integral equation (4) when $f(x)$ is given for positive integral values of x is known as the Problem of the Moments and is of some importance in investigations on the Law of Error.[3] The equation has been studied in these circumstances by Stieltjes,[4] in his famous researches on continued fractions. He shows that the solution of the equation is not unique unless a number of restrictions, indicated by the properties of an associated divergent series, are imposed upon the functions f and ϕ. The results of Stieltjes are expounded and generalised by Borel in his book on divergent series.

Stieltjes is also led in the course of his researches to a solution of the equation

$$f(x) = \int^{\infty} \frac{\phi(t)dt}{x+t}$$

Integral equations of the form (1) are of considerable importance in the theory of divergent series which has been developed by Borel,[5] le Roy,[6] Barnes,[7] Hardy,[8] Cunningham,[9] and others. An excellent account of the theory is given in Bromwich's 'Infinite Series.' A divergent series $\Sigma\, a_n x^n$ is associated with a function

$$\phi(xt) = \Sigma\, a_n \frac{x^n t^n}{\underline{/n}}$$

and finally with the function

$$f(x) = \int_0^{\infty} e^{-t}\phi(xt)dt.$$

Many interesting properties of these integrals are given in papers by the authors just mentioned.

Lerch[10] has shown that if an integral of the type

$$f(n) = \int_0^{\infty} e^{-nt}\phi(t)dt$$

[1] *Werke* (Weber), p. 140.

[2] *Acta Math.*, 1902, vol. xxv.; *Math. Ann.*, 1910, Bd. 68, Heft 3.

[3] See for instance the papers by F. Y. Edgeworth, *Camb. Phil. Trans.*, 1904, vol. xx.

[4] *Annales de Toulouse*, 1894, t. 8; 1895, t. 9.

[5] *Leçons sur les séries divergentes.* Paris (1901).

[6] *Annales de Toulouse* (2), t. 2 (1902), p. 317.

[7] *Phil. Trans. A.*, vol. cxcix., pp. 411–500.

[8] *Quarterly Journ.*, vol. xxxv. (1903), p. 22; *Cambr. Phil. Trans.*, vols. xix–xxi.

[9] *Proc. Lond. Math. Soc.* ser. 2, vol. iii. (1904), p. 161.

[10] *Acta Math.*, 1903, p. 339.

exists for any real value of x, say $x = c$, then it exists for any real value of x greater than c.

Pincherle,[1] on the other hand, has established the more general theorem that if the integral

$$\int_o^1 t^{x-1}\phi(t)dt$$

converges for $x = a$, it must converge for every finite value of x whose real part is greater than or equal to a. Pincherle assumes that $\phi(t)$ is finite and continuous in the interval $o \leq t \leq 1$, but this restriction has been removed by Landau.[2]

2. *Fourier's Theorems.*

The name of Fourier is greatly honoured among mathematicians for his researches in the conduction of heat[3] wherein he was led to investigate the general problem of the expansion of an arbitrary function in a trigonometrical series, or as it is now called, a Fourier's series. This investigation is only of indirect importance in the theory of integral equations, but his discovery of the inversion formulæ

$$\left.\begin{aligned} f(s) &= \int_o^\infty \cos st.\phi(t)dt \\ \phi(t) &= \frac{2}{\pi}\int_o^\infty \cos st.f(s)ds \end{aligned}\right\} \quad . \quad . \quad (1)$$

$$\left.\begin{aligned} g(s) &= \int_o^\infty \sin st.\chi(t)dt \\ \chi(t) &= \frac{2}{\pi}\int_o^\infty \sin st.g(s)ds \end{aligned}\right\} \quad . \quad . \quad (2)$$

and of the double integral

$$\psi(x+o)+\psi(x-o) = \frac{2}{\pi}\int_o^\infty d\lambda \int_{-\infty}^\infty \cos \lambda(x-t)\psi(t)dt \quad . \quad . \quad (3)$$

must rank as the greatest discovery in the whole history of the subject.

The investigations connected with these formulæ are very numerous,[4] and various conditions for their validity have been obtained. The first sufficient set of conditions appear to have been given by P. du Bois

[1] *Annales de l'École normale supérieure*, 1905 (3), t. 22, pp. 9–68.

[2] See Nielsen's *Handbuch der Gamma Funktionen*, p. 325.

[3] *Théorie analytique de la chaleur*, Paris (1822). Fourier's researches were first presented to the Paris Academy in 1807, and afterwards gained the great mathematical prize in 1812.

[4] A good bibliography is given in Carslaw's *Fourier's Series and Integrals* which also contains a proof of the formula (3). Another proof is given in Bromwich's *Infinite Series*, arts. 19, 20, 169.

Reymond.[1] The conditions were simplified by C. Neumann,[2] Dini,[3] and C. Jordan.[4] The last-named proved equation (3) on the supposition that $\psi(x)$ is a bounded function of limited total fluctuation such that

$$\int_{-\infty}^{\infty} /\psi(x)/\,dx$$

is convergent. These have practically remained the standard conditions until the present time, but the results have been recently established under slightly different conditions by Hilb,[5] Weyl,[6] Orlando,[7] Hobson,[8] and Pringsheim.[9] A good account of the present state of the theory is given in Pringsheim's papers. The formulæ have been discussed by Hobson from the point of view of the Lebesgue integral. Cauchy[10] and Poisson[11] discussed the formulæ (3) by introducing a convergence factor $e^{-k\lambda}$, changing the order of integration and finally making k tend to zero. This enables us to use the formula in cases when the integrals are not convergent without the factor $e^{-k\lambda}$. The method has been discussed by Boole[12] and other writers, and has been extended to other integral formulæ by Sommerfeld,[13] Hardy,[14] and Orr.[15]

3. *Applications of Fourier's Formulæ.*

Fourier's formulæ are of very great importance in all branches of mathematical physics in which the phenomena are expressed by means of linear partial differential equations. Whenever the equations possess solutions of the form

$$F(a,\xi,\eta\ .\ .\ .) \cos (at + \epsilon)$$

the solution may be generalised by Fourier's theorem. The method consists in multiplying by an arbitrary function of a and integrating between o and ∞. The introduction of the boundary conditions peculiar to the problem then leads to an integral equation for the unknown function, and this may be solved by Fourier's inversion formula. This method of reducing a problem in partial differential equations to the solution of an integral equation is of very wide application, and the integral equations which occur in this way are of primary importance. It also happens that in many cases the inversion formula can be expressed in a concise form.

Cauchy's method of solving partial differential equations by means of definite integrals is founded on an application of Fourier's theorem, or at least the analogous theorem in several variables.

[1] *Math. Ann.*, Bd. 4, pp. 362–390; *Crelle*, Bd. 79.

[2] *Ueber die nach Kreis-, Kugel-, und Cylinder-Functionen fortschreitenden Entwickelungen*, Leipzig (1881).

[3] *Serie di Fourier*, Pisa (1880).

[4] *Cours d'Analyse*, t. 2, Paris (1894).

[5] *Math. Ann.*, 1908, Bd. 66, heft 1.

[6] *Dissertation Göttingen*, 1908.

[7] *Rend. Lincei*, October 1908, vol. xviii., 2nd ser., 1909.

[8] *Proc. Lond. Math. Soc.*, 1908. Theory of Functions of a Real Variable Ch.

[9] *Jahresbericht der Deutsch. Math. Ver.*, 1907, Bd. 16; *Math. Ann.*, 1910, Bd. 68, pp. 367–408.

[10] *Mémoire sur la théorie des Ondes*, 1815.

[11] *Ibid.*, 1816.

[12] *Trans. Irish Acad.*, vol. 21 (1848).

[13] *Dissertation Königsberg*, 1891.

[14] *Camb. Phil. Trans.*, vol. xxi. No. 1, pp. 1–48.

[15] *Proc. Irish Acad.*, 1909, vol. xxvii., Sect. A.

Kirchhoff[1] made an interesting application of Fourier's formulæ when establishing the law of radiation which bears his name. In order to show that the law is valid for each separate wave-length he had to prove that the equation

$$\int_{o}^{\infty} \sin^4 \frac{p}{\lambda}\, \phi(\lambda) d\lambda = o$$

could not be satisfied for every positive value p of the thickness of a transparent plate unless $\phi(\lambda)$ was identically zero. The proof depended on a use of Fourier's formula.

Fourier's formulæ have many interesting applications in physical optics.[2] Some of these depend upon the use of a formula due to Rayleigh[3] and extended by Schuster.[4]

If

$$A_1(x) = \int_{-\infty}^{\infty} \cos xt\phi(t)dt \qquad B_1(x) = \int_{-\infty}^{\infty} \sin xt\phi(t)dt$$

$$A_2(x) = \int_{-\infty}^{\infty} \cos xt\psi(t)dt \qquad B_2(x) = \int_{-\infty}^{\infty} \sin xt\psi(t)dt$$

then

$$\int_{-\infty}^{\infty} \phi(t)\psi(t)dt = \frac{1}{\pi}\int_{o}^{\infty} [A_1(x)A_2(x) + B_1(x)B_2(x)]dx.$$

Schuster has made an extensive use of this formula in a study of interference phenomena. The formula has been extended to integrals analogous to those of Fourier by H. Weyl.[5]

Some very interesting applications of Fourier's theorem to the evaluation of definite integrals containing Bessel's functions have been made by Macdonald.[6]

Extensions of Fourier's Formulæ.

The following generalisation of Fourier's theorem was obtained by Liouville[7] and Hamilton.[8] If

$$\psi(x) = \int_{o}^{x} \phi(x)dx$$

is such that $\psi(x)$ never exceeds a certain value and

[1] *Ann. Phys. Chem.*, 1860, 109, p. 275.

[2] See, for instance, E. T. Whittaker, *Monthly Notices of the Royal Astronomical Society*, Nov. (1906), p. 85. Sir J. J. Thomson, *Phil. Mag.*, vol. xiv. (1907), p. 217. A. Eagle, *Phil. Mag.* (6), vol. xviii. (1909), p. 787. These three papers deal with the radiation from hot bodies.

[3] *Phil. Mag.*, 1889.

[4] *Ibid.*, 1894.

[5] *Dissertation Göttingen*, 1908.

[6] *Proc. Lond. Math. Soc.*, vol. xxxv. (1903).

[7] *Liouville's Journal*, 1836, vol. i., pp. 102–105.

[8] *Irish Trans.*, 1843, vol. xix.

$$\int_{-\infty}^{\infty}\frac{\psi(x)}{x}\,dx$$

has a value A which is neither zero nor infinite, then

$$f(x) = \frac{1}{A}\int_{0}^{\infty}dz\int_{-\infty}^{\infty}\phi[z(y-x)]f(y)dy \quad . \quad . \quad . \quad (1)$$

Hamilton gave as an example the case when $\phi(z)$ is the Bessel's function,

$$\phi(z) = \frac{d}{dz}J_1(z),$$

and introduced the idea of a fluctuating function. The general formula (1) has been established under certain limitations by Du Bois Reymond [1] and in a more general manner by Dr. Hobson [2] in a profound memoir which contains proofs of many important theorems.

In 1862 C. Neumann gave a formula involving Bessel's functions which is a generalisation of Fourier's theorem, and some years later Hankel [3] obtained the beautiful formulæ—

$$f(x) = \int_{0}^{\infty}J_v(xt)t\phi(t)dt$$

$$\phi(t) = \int_{0}^{\infty}J_v(xt)xf(x)dx$$

which contain Fourier's formulæ as a particular case. These formulæ were discovered independently by Sonine.

Proofs of Hankel's formulæ have been given by Du Bois Reymond,[4] Basset,[5] Nielsen,[6] and Orr.[7] The formulæ have been discussed with the aid of convergence factors by Sommerfeld [8] and Hardy.[9] Weyl [10] has established them by a general method appropriate for dealing with singular integral equations.

A remarkable extension of Fourier's formulæ has been obtained by Heaviside in his electrical researches.[11] If b is defined in terms of u by means of the equation

$$\tan b = \phi(u)$$

where $\phi(u)$ is a given odd function of u, then an arbitrary function

[1] Crelle's *Journal*, Bd. 69, 1868; Bd. 79, 1875.
[2] *Proc. Lond. Math. Soc.*, 1909, ser. 2, vol. vii.
[3] *Math. Ann.*, Bd. 8, 1875, p. 471.
[4] *Proc. Lond. Math. Soc.*, 1909, ser. 2, vol. vii.
[5] *A Treatise on Hydrodynamics*, 1888, vol. ii.
[6] *Handbuch der Cylinderfunktionen*, 1904 (Leipzig).
[7] *Proc. Roy. Irish Acad.*, 1909.
[8] *Dissertation Königsberg*, 1891.
[9] *Cambr. Phil. Trans.*, vol. xxi., p. 44.
[10] *Dissertation Göttingen*, 1908.
[11] *Electrical Papers*, vol. i., pp. 122, 158.

$f(x)$ which is subject to certain restrictions can be expressed in the form

$$f(x) = \frac{2}{\pi} \int_0^\infty \int_0^\infty \sin(ux + b) \sin(u\xi + b) f(\xi) du d\xi.$$

A somewhat analogous result has been obtained recently by Orr.

If $C(\lambda)$ and $S(\lambda)$ are two polynomials such that the values of λ for which $C(\lambda) + i S(\lambda)$ in zero have negative imaginary parts, and $f(x)$ is a function which satisfies Dirichlet's conditions and is such that

$$\int_0^\infty f(x) dx$$

is convergent, then—

$$\int_{-\infty}^\infty \frac{C(\lambda) \cos \lambda x + S(\lambda) \sin \lambda x}{C(\lambda) + iS(\lambda)} \int_0^\infty e^{i\lambda u} f(u) du$$

$$= \frac{\pi}{2} \{f(x+0) + f(x-0)\} \quad . \quad x > 0$$

$$= \pi \frac{C(\infty)}{C(\infty) + iS(\infty)} f(x+0) \quad . \quad x = 0$$

4. *Abel's Integral Equation.*

In 1826 Abel gave the solution of the integral equation

$$f(x) = \int_a^x \frac{u(\xi) d\xi}{(x-\xi)^\lambda} \qquad \begin{matrix} 0 < \lambda < 1 \\ f(a) = 0 \end{matrix} \quad . \quad . \quad (1)$$

in a form equivalent to

$$u(z) = \frac{\sin \lambda\pi}{\pi} \int_a^z \frac{f'(x) dx}{(z-x)^{1-\lambda}} \quad . \quad . \quad . \quad (2)$$

He obtained the particular case of the equation in which $\lambda = \frac{1}{2}$ in the solution of the dynamical problem of finding the form of a curve such that the time a particle takes to slide down the curve from an arbitrary point to the lowest point may be a given function of the arc described.[1] This problem contains the problem of the tautochrone as a particular case, and is analytically equivalent to the problem of finding a surface of revolution on which the geodesics satisfy certain conditions. The case in which the surface has an equator and all the geodesics are closed curves has been solved by Darboux.[2]

Another form of the integral equation had been obtained previously by Poisson[3] in some researches on the distribution of temperature in a conducting sphere, but was left unsolved. It was subsequently solved

[1] *Collected Works*, p. 11. The paper was published in Christiania in 1823. See also *Crelle*, vol. i., 1826, p. 153. [2] *Théorie générale des surfaces*, t. 3, pp. 5–7.
[3] *Journal de l'École Polytechnique*, 1821, 19, p. 299.

by Liouville,[1] who appears to have obtained the solution quite independently of Abel.

Liouville connected the equation with many interesting problems in geometry and analysis, and gave practically a rigorous proof of the inversion formula

$$u(z) = \frac{\sin \lambda\pi}{\pi} \frac{d}{dz} \int_a^z \frac{f(x)dx}{(z-x)^{1-\lambda}} \quad . \quad . \quad . \quad (3)$$

which holds if $f(x)$ is continuous in an interval $a \leq x \leq b$ if $f(a) = 0$, and if the integral in the last equation possesses a continuous derivative, so that the function $u(z)$ given by the formula is continuous. It can be shown that there is only one continuous solution of the equation. The transition from formula (3) to (2) can be effected when $f(x)$ possesses a finite derivative which has only a finite number of discontinuities in the interval $(a \leq x \leq b)$.

The case in which $f(a) \neq 0$ has been considered by Goursat.[2] If $f(x)$ satisfies the foregoing conditions, the solution is given by

$$u(z) = \frac{\sin \lambda\pi}{\pi} \cdot \frac{f(a)}{(z-a)^{1-\lambda}} + \frac{\sin \lambda\pi}{\pi} \int_0 \frac{f'(x)dx}{(z-x)^{1-\lambda}}.$$

Careful derivations of these results are given in Bôcher's tract on integral equations.

Liouville first studied the integral equation in 1833 in connection with the theory of fractional differentiations and integrations. He was thus led to some analogous forms of the equation in which λ is negative, and gave the formula

$$\int_0^\infty x^{n-1} \phi(x+a)dx = (-1)^n \Gamma(n) \left(\frac{d}{da}\right)^{-n} \phi(a),$$

which, however, is only valid when a large number of conditions are satisfied.

Boole[3] extended Liouville's results and gave the following general formula for the solution of the equation :—

$$\psi(a) = \int_0^a (a-x)^{n-1}\phi(x)dx,$$

where n is a positive fraction.

$$\phi(a) = \frac{a^{i-n}}{\Gamma(n)\Gamma(i-n)} \left(\frac{d}{da}\right)^i \int_0^1 v^{-i} (1-v)^{i-n-1} \psi(av)dv,$$

i being the integer next above n and $i-1$ being less than the first exponent in the ascending development of $\psi(a)$. This formula is

[1] *Journal de l'École Polytechnique*, 1835. [2] *Acta Math.*, 1903.
[3] *Camb. Math. Journ.*, 1845, vol. iv., pp. 82–87.

closely connected with Riemann's formula for fractional differentiation, viz.,

$$\left(\frac{d}{dx}\right)^s a(x) = \frac{1}{\Gamma(m-s)} \left(\frac{d}{dx}\right)^m \int_a^x (x-z)^{m-s-1} a(z) dz.$$

Abel's integral equation occurs in many investigations, some of which are of a physical character. It is used in the derivation of Schlömilch's expansion [1] of an arbitrary function in a series of Bessel's functions of the type

$$f(x) = \Sigma a_n J_o(nx).$$

A good account of this theory is given in Whittaker's 'Analysis' and in Nielsen's 'Cylinderfunktionen,' where another proof of Abel's formula is obtained. The proof is intimately connected with an artifice due to Poisson [2] in which an integral over an octant of a spherical surface is expressed in two different forms, *e.g.*,

$$\int_o^{\frac{\pi}{2}} \int_o^{\frac{\pi}{2}} f'(\sin\theta \sin\phi) \sin\theta d\theta d\phi = \int_o^{\frac{\pi}{2}} \int_o^{\frac{\pi}{2}} f'(\cos\theta) \sin\theta \, d\theta d\phi$$

$$= \frac{\pi}{2}[f(1) - f(o)].$$

This artifice and its generalisations have been used to obtain proofs of Abel's formula by Tait,[3] Beltrami,[4] and Gwyther.

A form of Abel's equation has been used by Lamb in the solution of problems in hydrodynamics and the diffraction of light.

If $$f(\rho) = \int_o^\infty \chi\,(\rho \cosh u)\, du,$$

then $$\chi(\rho) = -\frac{2\rho}{\pi} \int_o^\infty f'(\rho \cosh u)\, du.$$

This formula is a particular case of the more general formula

$$g(y) = \int_y^c \frac{v(\eta) d\eta}{(\eta - y)^\lambda} \quad g(c) = o$$

$$v(\eta) = -\frac{\sin\lambda\pi}{\pi} \frac{d}{d\eta} \int_\eta^c \frac{g(y) dy}{(y-\eta)^{1-\lambda}}$$

which may be deduced from (3). The case in which $c = \infty$ corresponds to the case in which $a = o$, in (1), and can be examined without difficulty.

The last equation occurs in the solution of the problem proposed by Benndorf and Schuster of determining the velocity of propagation of an

[1] *Zeitschrift für Math. in Phyzik*, 1857. Recent investigations have been given by Gwyther, *Mess. Math.*, vol. xxiii., p. 97, and Miss Smith, *Amer. Trans.*, 1907.

[2] *Journ. de l'École Polytechnique*, 1821, Cah. 19.

[3] *Proc. Roy. Soc. of Edinburgh*, 1874; *Scientific Papers*, vol. i., p. 245.

[4] *Rend. Lomb.*, 1880, ser. 2, vol. xiii.

earthquake wave at different points of the earth on the supposition that the earth is symmetrical about its centre. This problem has been solved by G. Herglotz[1] and by the author.[2] The method has been applied to some recent observations by Wiechert and Geiger.[3]

Abel's equation has also been used by Boggio[4] to solve a differential-integral equation which occurs in the problem of the motion of a sphere in a viscous fluid. This equation has been obtained by Basset[5] and Picciati,[6] and was solved by the latter by a method of expansion. The results are of some physical interest, as it is proved that the motion of the sphere tends to become uniform, and then its limiting velocity is given by Stokes's law. A good account of the theory is given in a recent paper by Basset, 'Quarterly Journal' (1910).

5. *Integral Equations with Variable Limits.*

The idea of an integral equation in which a variable quantity occurs in one of the limits of the integral appears to have been first considered by Babbage,[7] although no method of solution was suggested.

Cauchy[8] in (1815) solved a special integral equation of this type by differentiation, but the first general method of solution appears to have been used by Poisson[9] in 1826. He obtained an equation of the form

$$g(t) = \phi(t) - \frac{4\pi k}{3}\int_o^t f'(t-\theta)\phi(\theta)d\theta \quad . \quad . \quad . \quad (1)$$

in which the unknown function ϕ appears both inside and outside the sign of integration. An equation of the form (1), in which the kernel is of the form $f'(t-\theta)$, will be called an integral equation of *Poisson's type*. Poisson solved the equation by expanding $\phi(t)$ in powers of k, thus obtaining an infinite series of multiple integrals, but he did not establish the convergence of the series.

This step was supplied by Liouville[10] in (1837). He arrived at the integral equation

$$g(t) = \phi(t) - \lambda\int_o^t \kappa(t,\theta)\phi(\theta)d\theta \quad . \quad . \quad . \quad . \quad (2)$$

in his classical researches on linear differential equations and the expansion in the so-called oscillating functions. These functions satisfy a differential equation of the Sturm-Liouville type, viz.,

$$\frac{d}{dx}\left(\kappa\frac{dV}{dx}\right) + (gr - l)V = o,$$

which occurs in the theory of the conduction of heat in a heterogeneous bar and in many other problems of mathematical physics. The set of functions is obtained by taking the different possible values of the

[1] *Phys. Zeitschr.*, 1907. [2] *Phil. Mag.*, 1910. [3] *Phys. Zeitschr.*, 1910.
[4] *Rend. Lincei*, 1907. [5] *Hydrodynamics*, vol. ii. [6] *Rend. Lincei*, 1907.
[7] *Memoirs of the Analytical Society*, Preface, 1813.
[8] *Mémoire sur la théorie des Ondes.*
[9] *Mémoire sur la théorie du magnétisme en mouvement.* Œuvres t. 3, No. 5, pp. 41–72. [10] Liouville's *Journal*, vol. ii.

parameter r for which the equation possesses a solution satisfying the boundary condition of the problem.

The equation (2) was also used by Caqué[1] in his researches on differential equations, and he expressed the solution in the concise form

$$\phi(t) = g(t) + \lambda\int_0^t \mathrm{K}(t,\theta)g(\theta)d\theta$$

where $\mathrm{K}(t, \theta)$ is the so-called *solving function*.

The general study of the equation was, however, taken up by Volterra[2] in 96), and the theory was at the same time applied to the equation (18

$$f(t) = \int_0^t \kappa(t,\theta)\phi(\theta)d\theta \quad . \quad . \quad . \quad . \quad . \quad (3)$$

which had been previously studied by him,[3] and treated as the limit of a system of linear equations.

The last equation is named after Volterra in honour of his extensive researches on the subject.

The general method of treating the integral equations (2) and (3) was also discussed in 1895 by Le Roux in connection with his researches on partial differential equations. Abel's integral equation, which is a particular case of equation (3), had been extended by Sonine[4] in 1884. Volterra obtained a more general result, and connected it with his general theory. He also considered equations in which there are two variable limits in the integral.[5]

These equations and analogous ones have been treated subsequently by Holmgren,[6] Lalesco,[7] Picard,[8] and other writers. The connection with differential equations has been developed by Fuchs,[9] Dini,[10] Lalesco and the author.[11]

The general formula for the solution of the integral equation

$$f(x) = \phi(x) - \lambda\int_0^x \kappa(x,t)\phi(t)dt$$

$$\phi(x) = f(x) + \lambda\int_0^x \mathrm{K}(x,t)f(t)dt,$$

[1] Liouville's *Journal*, 1864, vol. ii., t. 9, p. 185.

[2] *Torino Atti*, 1896, pp. 311, 400, 557, 693; *Annali di Matematica*, 1897.

[3] *Il Nuovo Cimento*, 1884, t. 4, p. 49; *Rend. Lincei*, 1884, ser. 3ª, t. 8.

[4] *Acta Mathematici*, t. 4. Another generalisation was given by P. G. Tait, *Scientific Papers*, vol. i., p. 245; *Edin. Proc. Roy. Soc.*, 1874.

[5] Equations of this type have been also considered by Picard, *Comptes rendus*, 1909.

[6] *Torino Atti*, 1900, t. 35; *Upsala Memoirs*, 1900, t. 3.

[7] Liouville's *Journal*, 1908.

[8] *Comptes rendus*, 1904, p. 245; *ibid.*, 1909.

[9] *Annali di Matematica*, ser. (2), vol. iv., pp. 36–49 (1870).

[10] *Ibid.*, 1899, ser. 3, t. ii., pp. 297–324; t. iii., pp. 125–183; t. xi., p. 385.

[11] *Proc. London Math. Soc.*, 1906, p. 107; Darboux's *Bull.*, 1906.

where
$$K(x,t) = \kappa(x,t) + \sum_{2}^{\infty} \lambda^{r-} K_x(x,t)$$

and
$$\kappa_r(x,t) = \int_t^x \kappa_m(x,y)\kappa_{r-m}(y,t)dy$$
$$\kappa_1(x,t) = \kappa(x,t).$$

The series for $K(x,t)$ is convergent for all values of λ if $f(x)$ and $\kappa(x,t)$ are bounded integrable functions, and there is only one bounded integrable solution of the equation.

The integral equation
$$f(x) - f(a) = \int_a^x H(x,y)\phi(y)dy$$

may be reduced to the previous one by differentiation, for we have
$$f'(x) = H(x,x)\phi(x) + \int_a^x \frac{\partial H(x,y)}{\partial x}\phi(y)dy.$$

It is convenient now to assume that $/H(x,x)/$ has a lower limit which is different from zero in an interval $a < x < a + A$, and that the function
$$\frac{1}{H(y,y)} \quad \frac{\partial H(x,y)}{\partial x}$$

is a bounded integrable function in this interval. The previous method may then be applied to determine the function
$$\psi(x) = H(x,x)\phi(x).$$

Volterra's extension of Abel's theorem is as follows:—

If
$$f(y) - f(a) = \int_a^y \frac{G(x,y)}{(y-x)^\lambda}\phi(x)dx. \qquad (\lambda<1)$$

where $f(y)$ and $f'(y)$ are finite and continuous for $a < y < a + A$, and if $G(x,y)$ and $\frac{\partial G}{\partial y} = G_2(x,y)$ are finite and continuous for all values of x and y contained in the interval $(a, a + A)$ and the absolute value of the lower limit of $g(y) = G(y,y)$ is different from zero, then here is only one finite continuous function $\phi(x)$ which satisfies the equation for $a < x < a + A$, and this solution is given by the formulæ
$$\phi(z) = \frac{\sin\lambda\pi}{\pi}\frac{1}{g(z)}\int_a^z f'(x)\sum_0^\infty T_i(x,z)dx$$
$$S_o(y,z) = \frac{\sin\lambda\pi}{\pi}\frac{1}{g(z)}\int_y^z G_2(y,\xi)\left(\frac{\xi - y}{z - \xi}\right)^{1-\lambda}\frac{d\xi}{z-y}$$
$$T_o(x,z) = \frac{1}{(z-x)^{1-\lambda}}$$
$$T_i(x,z) = \int^x S_o(\xi,z)T_{i-1}(x,\xi)d\xi$$

When $H(x,y)$ vanishes for $x = y$ the results take a different form, and we have the following theorem :—

If
$$f(y) = \int_o^y \phi(x) H(x,y) dx \quad a > y > o$$

where
$$f(y) = y^{n+1} f_1(y)$$
$$H(x\,y) = \sum_o^n{}_i\, a_i x^i y^{n-i} + \sum_o^{n+1}{}_i\, x^i y^{n+1-i} L_i(x,y)$$

and the quantities a_i are constants.

If $f_1(y)$, $L_i(x,y)$ and their derivatives with regard to y are finite and continuous for $(o < x < y)$ and $(o < y < a)$, and if $H(y,y)$ does not vanish except when $y = o$, there is one and only one finite and continuous function which satisfies (25) in the case when the roots of the algebraic equation of degree n.

$$\frac{a_o}{\lambda - 1} + \frac{a_1}{\lambda - 2} + \quad . \quad . \quad \frac{a_n}{\lambda - n - 1} = o$$

are finite and different from one another and have their real parts positive. If one or more of the roots have their real part negative and the roots are otherwise finite and distinct, the problem of finding a function $\phi(x)$ which satisfies the integral equation is indeterminate. A useful criterion for determining whether an equation of the above type has roots with only positive real parts has been given by Hurwitz.[1]

Further investigations connected with the case in which $H(x,x)$ vanishes have been made by Holmgren[2] and Lalesco.[3] The latter considers the particular case in which $H(x,y)$ is a polynomial of the n^{th} degree in x, and shows that the integral equation may be reduced to a linear differential equation of the n^{th} order by differentiation. The algebraic equation for λ is then identical with the indicial equation of the adjoint differential equation. The results are then applied to the study of the general case. Further investigations on the connection between linear differential equations and integral equations of Volterra's type have been made by Dini[4] and the author.[5] It may be shown without difficulty that a linear differential equation may be replaced by an integral equation of Volterra's type, and then, by applying a method of successive approximations, a series is obtained which represents a solution of the linear differential equation in the whole of the complex plane (excluding singularities). This method of proving the existence theorem is virtually due to Cauchy.[6]

When the conditions of Volterra's theorems are not satisfied the solution of the integral equation may not be unique and discontinuous solutions can enter. Thus Bôcher[7] gives the example—

[1] *Math. Ann.*, Bd. 46, p. 273.
[2] *Atti of the Turin Academy*, 1900, vol. xxxv., p. 570; *Upsala Memoirs*, 1900, vol. iii.
[3] Liouville's *Journal*, 1908, ser. 6, vol. iv., p. 125.
[4] *Annali di Matematica*, 1899, ser. 3, t. ii., pp. 297–324; t. iii., pp. 125–183 t. xi., p. 385.
[5] *Proc. London Math. Soc.*, 1906, p. 107; Darboux's *Bull.*, 1906.
[6] *Œuvres complètes*, 1[re] série, t. v., p. 394.
[7] *An Introduction to the Study of Integral Equations*, p. 17.

$$u(x) = \int_{o}^{x} \xi^{x \quad \xi} u(\xi) d\xi$$

of an equation which possesses a discontinuous solution

$$u(x) = x^{r-1}.$$

W. Kapteyn[1] has shown that a solution of the integral equation

$$f(x) = \int_{o}^{x} \mathrm{J}_o(x-y)\phi(y)dy$$

can be expressed in the form

$$\phi(y) = \frac{df}{dy} + \int_{o}^{y} \frac{\mathrm{J}_1(x-y)}{x-y} f(x)dx$$

It is interesting to compare this result with the formula given on p. 416, § 26.

6. *Physical Applications of the Equations with Variable Limits. Problems of Heredity and Hysteresis.*

Volterra has made use of an integral equation with variable limits in some researches on the equilibrium of a rotating mass of fluid,[2] and there are numerous applications of equations of this type to partial differential equations of the hyperbolic and parabolic type;[3] but the most interesting applications appear to be to problems of heredity in which a physical system exhibits phenomena of memory or hysteresis.

It has been remarked by Picard, in his article on 'La Mécanique classique et ses approximations successives,'[4] that mechanics can be divided into hereditary and non-hereditary mechanics. The latter deals with cases in which the future of a system depends only upon its actual state and the states which precede it but are separated from the momentary one only by an infinitesimal interval of time. The former deals with the case when any action leaves an impression on the system and the actual state depends upon all the preceding states.

The theory of mechanical problems of this type was commenced by Poisson in his Memoir on magnetism already referred to. He represented the components of magnetisation at time t by expressions of the type

$$\mathrm{A}(t) = \int_{o} f'(t-\theta)a(\theta)d\theta,$$

and arrived at the integral equation with variable limits cited in

[1] *Liège Memoirs*, 1906 (3), t. 6.

[2] *Acta Math.*, 1903.

[3] See, for instance, the researches of Le Roux, Holmgren, Goursat, *Annales de Toulouse*, 1904; Mason, *Math. Ann.*, 1908, Bd. lxv., p. 570; Myller, *Math. Ann.*, 1910, Bd. lxviii.

[4] *Rivista di Scienza*, vol. i., Bologna (1907).

Section 5. A somewhat similar procedure was adopted by Boltzmann [1] in his theory of elastic afterworking, and by Korn [2] in the study of the action of selenium cells.

A general theory of problems of this type has been developed by Volterra.[3] In 1887 he gave a general expansion theorem for a quantity which depends on all the values of another function in a given interval, and in his recent researches he has developed the theory of integro-differential equations,[4] which appear to be the type of equations usually required for the treatment of problems of hysteresis in electrodynamics and the theory of elasticity. It is found that in electrodynamics equations of Poisson's type are of special importance.

In problems of memory, when the state of a system is represented by an equation such as

$$\phi(t) = f(t) + \lambda \int_a^t \kappa(t,\theta) f(\theta) d\theta,$$

it is interesting to determine the sets of values of t and θ for which the function $\kappa\ (t,\ \theta)$ becomes infinite. If these are determined by an equation of the form

$$F(t,\theta) = o,$$

then the events which occurred at the particular times θ given by this equation are those whose effects will be emphasised at the given time t. The emphatic events will, however, generally change as t varies, unless it happens that the last equation is independent of t.

An interesting problem of heredity connected with the motion of an electron has been discussed by G. Herglotz [5] and P. Hertz.[6] The integral equations are in this case of the forms

$$f(t) = \phi(t) - \int_o \kappa(s)\phi(t-s)$$

$$\kappa(s) = 3 - 6s^2 \quad o \leq s \leq 1$$

and

$$f(t) = \phi(t) - \int_o^t \phi(t-s)\kappa(s) ds$$

$$\kappa(s) = 5 - 30s^2 + 30s^4 \quad o \leq s \leq 1$$

respectively, and are solved by a method of successive approximations. An interesting feature is the occurrence of solutions of the homogeneous equations of the form

$$\phi_h(t) = e^{-a_h ti}$$

[1] *Ann. Phys. Chem.* (Poggendorff), Ergzgsbd. 7 (1878); *Sitzungsberichte*, Vienna (1874).

[2] *Phys. Zeitschr.* (1909), p. 793.

[3] *Rend. Lincei*, 1909, vol. xviii., pp. 203, 295: 'L'inversion des intégrales définies.' 'Lectures at Clark University' (Teubner).

[4] Certain types of integro-differential equations have been considered by Picard, Lauricella, and Burgatti.

[5] *Gött. Nachr.*, 1903; *Math. Ann.*, 1908, Bd. 65.

[6] *Dissertation Göttingen*, 1904; *Math. Ann.*, 1908, Bd. 65. An account of the work is also given in a paper by G. F. C. Searle, *Proc. Roy. Soc. A.*, vol. lxxix., p. 550.

where the quanitties a_h are the roots of the transcendental equation

$$\chi(x)=\int_{o}^{1}\kappa(s)e^{ixs}ds=1.$$

The solving functions K(s), Q(s) are solutions of the equations

$$\kappa(t)=\mathrm{K}(t)-\int_{o}\mathrm{K}(t-s)\kappa(s)ds \qquad -\infty<t<+\infty$$

$$\kappa(t)=\mathrm{Q}(t)-\int_{o}^{t}\mathrm{Q}(t-s)\kappa(s)ds \qquad o<t<+\infty$$

respectively, and the solutions of the two equations (1) and (2) are given by the formulæ

$$\phi(t)=f(t)+\int_{-\infty}^{\infty}f(t-s)\mathrm{K}(s)ds \quad . \quad . \quad . \quad . \quad (\mathrm{I})'$$

$$\bar{\phi}(t)=\bar{f}(t)+\int_{o}^{t}f(s)\mathrm{Q}(t-s)ds \quad . \quad . \quad . \quad . \quad (\mathrm{II})$$

respectively, where $\bar{\phi}(t)$ is written for $\frac{1}{2}[\phi(t+o)+\phi(t-o)]$

There is also an expansion theorem :—

$$\phi(t+o)+\phi(t-o)=2i\sum_{h=1}^{\infty}\frac{\phi_h(t)}{\mathrm{X}'(a_h)}\int_{o}^{1}e^{\frac{isa}{h}}\phi(s)ds\int_{1-s}^{1}\kappa(n)e^{\frac{ira}{h}}dr$$

Herglotz's paper contains many other interesting results.

An interesting integral equation which is reducible to an equation of Poisson's type was obtained and solved by Beltrami [1] in some researches on the conduction of heat. The equation is

$$f(t)=\phi(t)-\frac{2}{\sqrt{\pi}}\int_{\frac{\omega}{\sqrt{t}}}^{\infty}\phi\left(t-\frac{\omega^2}{\theta^2}\right)e^{-\theta^2}d\theta$$

and its solution depends upon the fact that the operation

$$\mathrm{F}_{\omega}(t)=\frac{2}{\sqrt{\pi}}\int_{\frac{\omega}{\sqrt{t}}}^{\infty}f\left(t-\frac{\omega^2}{\theta^2}\right)e^{-\theta^2}d\theta$$

possesses the property.

$$\mathrm{F}_{\omega_1\omega'}(t)=\mathrm{F}_{\omega+\omega'}(t)$$

i.e., the effect of repeating the operation is simply to add the arguments. This result may be deduced from Borel's multiplication theorem given in Section 16.

[1] *Bologna Memoirs*, ser. 4, t. 8, pp. 291–326.

Beltrami's work has recently been extended by Césaro.[1]

P. Hertz has shown [2] that the theory of Einthoven's string galvanometer depends upon an integral equation of Poisson's type. The differential equation for the motion of the string, when the electromagnetic damping only is considered, is of the form

$$\frac{\partial^2\eta}{\partial t^2}=a^2\frac{\partial^2\eta}{\partial x^2}+\mathrm{F}(t)-b\int_o^l\frac{\partial\eta}{\partial t}\,dx$$

where a and b are constant. The initial conditions are of the type

$$\eta(o,x)=0. \qquad \left(\frac{\partial\eta}{\partial t}\right)_{t=o}=0.$$

The equation is solved according to Rayleigh's method by putting

$$\eta=\sum_1^\infty\gamma_\nu(t)\sin\frac{\nu\pi x}{l}$$

where $\qquad \gamma_\nu(o)=0. \qquad \dot\gamma_\nu(o)=0.$

Expanding F in a Fourier's series

$$\mathrm{F}=\Sigma\frac{4\mathrm{F}}{\nu\pi}\sin\frac{\nu\pi x}{l} \qquad (\nu=1,3,5\ldots)$$

and putting

$$\Phi(t)=\mathrm{F}(t)-\frac{2bl}{\pi}\left(\frac{\dot\gamma_1}{1}+\frac{\dot\gamma_3}{3}+---\right)=\mathrm{F}-6\int_o^l\frac{\partial\eta}{\partial t}\,dx$$

we obtain the integral equation

$$\mathrm{F}(t)=\Phi(t)+\int_o^t\mathrm{N}(t-\theta)\Phi(\theta)d\theta.$$

for the determination of $\Phi(t)$. The function $\mathrm{N}(t)$ is defined by the equation

$$\mathrm{N}(t)=\frac{8bl}{\pi^2}\Sigma\frac{1}{\nu^2}\cos\frac{a\nu\pi t}{l} \qquad (\nu=1,3,5\ldots)$$

and is such that $\frac{\partial\mathrm{N}}{\partial t}=+2ab$ or $-2ab$ according as t lies between $2m-1)\frac{l}{a}$ and $\frac{2ml}{a}$ or between $\frac{2ml}{a}$ and $\frac{(2m+1)l}{a}$.

Hertz also considers the more general equation

$$\frac{\partial^2\eta}{\partial t^2}=a^2\frac{\partial^2\eta}{\partial x^2}-g\frac{\partial\eta}{\partial t}+\mathrm{F}(t)-b\int_o^l\frac{\partial\eta}{\partial t}dx$$

which corresponds to the case when the resistance of the air is taken into account.

[1] *Bull. de Roy. Acad. Belgique*, 1902, p. 387; *Comptes rendus*, Naples, ser. 3, t. 7, pp. 284–289.

[2] *Zeitschrift für Math. in Phys.*, 1909, Bd. 58.

7. *The Problem of Dirichlet and the Method of Successive Approximations.*

The so-called problem of Dirichlet,[1] which is to establish the existence of a potential function having given values round a contour, was originally solved by Gauss and Lord Kelvin by means of the calculus of variations, the function V which makes the integral

$$\iiint\left[\left(\frac{\partial V}{\partial x}\right)^2+\left(\frac{\partial V}{\partial y}\right)^2+\left(\frac{\partial V}{\partial z}\right)^2\right]dxdydz$$

a minimum being the required potential function. This proof was considered sufficient by Riemann[2] but was rejected by Weierstrass.[3]

In 1870 C. Neumann[4] invented his famous method of the arithmetical mean in which the solution of the problem was really reduced to that of an integral equation of the second kind.

The reduction of various potential problems to integral equations of the second kind depends upon the fundamental properties of potentials of simple and double layers.

Let the symbol $f(p)$ be used to denote a function of the co-ordinate or parameters which determine the position of a point P, then if r is the distance between two points A, B and we put

$$g(a,b)=\frac{1}{\pi}\log\left(\frac{1}{r}\right) \text{ for problems in a plane}$$

$$=\frac{1}{2\pi r} \quad \text{for problems in space;}$$

$$h(s,p)=\frac{\partial}{\partial n}g(s,p)=\frac{1}{\pi}\frac{\cos\phi}{r} \text{ in the plane}$$

$$=\frac{1}{2\pi}\frac{\cos\phi}{r^2} \text{ in space;}$$

ϕ being the angle between the radius vector and the normal at a point S on the boundary, then

$$V(p)=\int g(p,s)\rho(s)ds$$

$$W(p)=\int\mu(s)h(s,p)ds$$

are the potentials of simple and double layers of strength, $\rho(s)$, $\mu(s)$ respectively.

The potentials of a simple layer is continuous over the boundary, but

[1] The problem was considered originally by Gauss (1839), Kelvin (1847), and Dirichlet (1856). The name Dirichlet's principle was introduced by Riemann, *Ges. Werke*, pp. 35–39, pp. 96–98.

[2] *Diss.* § 16. *Fonctions abéliennes, Avant-Propos*, p. 111.

[3] *Ueber dass ogenannte Dirichlet'sche Prinzip, Königl. Akad. der Wiss.*, Berlin, July 14 (1870); *Werke*, ii., p. 49 (1903).

[4] *Leipziger Berichte*, 1870; *Untersuchungen über das logarithmische und Newton'sche Potential*, Leipzig (1877), p. 139.

the values of the normal derivatives $\frac{\partial V_o}{\partial n}$, $\frac{\partial V_i}{\partial n}$ just outside and just inside the boundary are connected by the equations

$$\tfrac{1}{2}\left[\frac{\partial V_o}{\partial n} - \frac{\partial V_i}{\partial n}\right] = \rho(s)$$

$$\tfrac{1}{2}\left[\frac{\partial V_o}{\partial n} + \frac{\partial V_i}{\partial n}\right] = \int h(s,\sigma)\rho(\sigma)d\sigma$$

The potential of a double layer is discontinuous at the boundary, its values, W_i, W_o, just inside and just outside being connected by the equations [1]

$$\tfrac{1}{2}[W_i - W_o] = \mu(s)$$

$$\tfrac{1}{2}[W_i + W_o] = \int \mu(\sigma)h(\sigma,s)d\sigma.$$

Poincaré enunciates the two problems of potential theory in the following form—

I. *To find a potential of a double layer which satisfies the condition*

$$\tfrac{1}{2}[W_i - W_o] - \frac{\lambda}{2}[W_i + W_o] = f(t)$$

at a regular point t of the boundary.

II. To find a potential of a simple layer which satisfies the condition

$$\tfrac{1}{2}\left[\frac{\partial V_o}{\partial n} - \frac{\partial V_i}{\partial n}\right] - \frac{\lambda}{2}\left[\frac{\partial V_o}{\partial n} + \frac{\partial V_i}{\partial n}\right] = f(t).$$

These problems are reduced at once to the solution of the adjoint integral equations

$$\mu(t) - \lambda\int\mu(s)h(s,t)ds = f(t)$$

$$\rho(t) - \lambda\int h(t,s)\rho(s)ds = f(t).$$

For $\lambda = -1$ we have the internal problem of Dirichlet and the external hydrodynamical problem; for $\lambda = +1$ we have the external problem of Dirichlet and the internal hydrodynamical problem. Poincaré calls the general problem in which the parameter λ occurs the problem of Neumann. The introduction of the parameter λ by Poincaré is really a very important step.

In Neumann's method of solution the functions $\mu(t)$, $\rho(t)$ are determined by expanding them in powers of λ and determining the coefficients in succession. This method, which has been applied to differential equations since the time of Laplace,[2] has been called by Picard the *method of successive approximations.* The method has been greatly

[1] These relations are of course classical. Careful proofs of them are given by Plemelj, *Monatshefte für Math. u. Physik*, 1904, and in a little book by Viscount d'Adhémar, *Sur l'équation de Fredholm et les problèmes de Dirichlet et de Neumann*, (Paris) 1909.

[2] *Œuvres*, t. 10, p. 54, 1779.

developed by C. Neumann, Poincaré,[1] Picard[2] and Korn, and applied to problems in elasticity by E. F. Cosserat,[3] Korn,[4] and others. A good account of the method is given in E. R. Neumann's prize memoir (Leipzig, 1905), and in Korn's 'Abhandlungen zur Potential Theorie' (Berlin, 1901). Neumann's method solves the problem of Dirichlet for the case of a *convex* region, and the solution may be extended to regions of a more general character by Schwarz's method of alternation. Further researches in this direction have been made by A. C. Dixon.[5]

Other methods of solving Dirichlet's problem given by Kirchhoff,[6] Robin,[7] and Stekloff,[8] are closely allied to Neumann's method. Poincaré[9] has devised a method in which a series of functions is formed, each of which satisfies the boundary condition, and whose limit satisfies the differential equation as well. Hilbert[10] has shown that the old method of the calculus of variations can be remodelled and made quite rigorous, thus realising the hope expressed by Brill and Noether that the principle of Dirichlet would some day be revived. Generalisations of Dirichlet's problem to partial differential equation of elliptic type have been given by Segre Bernstein.[11]

The advent of Fredholm's method of solving the integral equation of the second kind has provided a new and beautiful method of solving Dirichlet's problem, and has led to many new developments. It is true that the method does not apply to the general case. For instance, Kellogg remarks that if the boundary is a rectangle, Fredholm's series does not converge. It is probable, however, that by some modification of the method this difficulty may be overcome.

Neumann's solution of the equation

$$f(s) = \phi(s) - \lambda\int_a^b \kappa(s,t)\,\phi(t)\,dt$$

may be expressed in a concise form by introducing the *iterated functions*

$$\kappa_2(s,t) = \int_a^b \kappa(s,x)\kappa(x,t)dx,$$

$$\kappa_3(s,t) = \int_a^b \kappa(s,x)\kappa_2(x,t)dx,$$

$$\kappa_n(s,t) = \int_a^b \kappa(s,x)\kappa_{n-1}(x,t)dx,$$

[1] *Acta Math.*, 1897; *Rend. Palermo*, 1894.

[2] *Traité d'Analyse*, 2nd Ed., vol. i. [3] *Comptes rendus*, t. 133 (1901).

[4] *Ann. de Toulouse*, 1908; *Ann. de l'École Normale Supérieure*, 1908.

[5] *Cambr. Phil. Trans.*, vol. xix., part 2, p. 203; *Proc. London Math. Soc.*, ser. 2, vol. i., p. 415 (1903).

[6] *Acta Math.*, 14, 1890, p. 180. [7] *Comptes rendus*, 104, 1887, p. 1834.

[8] *Ibid.*, 125, 1897, p. 1026.

[9] *Théorie du potential Newtonien*, Paris (1899), p. 260.

[10] *Math. Ann.*, Bd. 59, 1901.

[11] *Comptes rendus*, Nov. 1903; *Math. Ann.*, Bd. 62, 1904; Bd. 69, 1910; recent papers on Dirichlet's problem have been published by Fubini, *Rend. Palermo* (1907), and Lebesgue, *ibid.* (1909).

and the *solving function*

$$K(s,t) = \kappa(s,t) + \lambda\kappa_2(s,t) + \lambda^2\kappa_3(s,t) + \ldots$$

This series has a finite radius of convergence if $\int_a^b [\kappa(x,y)]^2 dy$ and $\int_a^b [\kappa(x,y)]^2 dx$ are always finite,[1] or if $\int_a^b\int_a^b \kappa(x,y)dxdy$ is convergent. If λ has a value whose modulus is less than the radius of convergence and $f(s)$ is bounded, the solution of the integral equation is given *uniquely* by the equation

$$\phi(s) = f(s) + \lambda\int_a^b K(s,t) f(t)dt,$$

and the relation between the functions $\kappa(s,t)$, $K(s,t)$ is of a reciprocal nature. These formulæ are established for other values of λ by Fredholm's method.

It is, in fact, a consequence of Poincaré's researches that the functions $\phi(s)$, $K(s,t)$ are *meromorphic functions* of λ, and Fredholm states at the beginning of his paper that his method provides a direct method of obtaining these functions in the canonical form of the ratio of two integral functions of λ.

8. *Green's Functions.*

The function which Neumann has called the Green's function was first introduced by George Green in his essay on the application of mathematical analysis to the theories of electricity and magnetism (1828), p. 26.

The Green's function $G(x,y,z;\ \xi,\eta,\zeta)$ is defined to be a function which satisfies Laplace's equation $\nabla^2 V = 0$, and is a regular analytic function of x,y,z, at all points inside (or outside) the surface S with the exception of the point (ξ,η,ζ). In the neighbourhood of this point

$$G - \frac{1}{\sqrt{(x-\xi)^2 + (y-\eta)^2 + (z-\zeta)^2}} \quad . \quad . \quad (1)$$

s a regular analytic function. On the boundary of S, G satisfies a linear condition such as $G = 0$, $\frac{\partial G}{\partial n} = 0$, or $\frac{\partial G}{\partial n} + hG = 0$. The fundamental property of the Green's function is that a solution of $\nabla^2 V + f(x,y,z) = 0$ which satisfies the same boundary condition as G, is given by the formula

$$V(x,y,z) = \iiint_s G(x,y,z;\ \xi,\eta,\zeta) f(\xi,\eta,\zeta)d\xi d\eta d\zeta.$$

This equation may be regarded as an integral equation for the determination of f when V is given. If V satisfies the boundary condition

[1] E. Schmidt, *Math. Ann.*

and has continuous second derivatives, then f is determined by the formula

$$f = -\nabla^2 V.$$

The Green's function was used primarily to solve the problem of determining a potential function which takes given values $\bar{V}$ over the boundary. The function G is now defined by the boundary condition $G = 0$, and V is determined by means of the formula

$$4\pi V(x,y,z) = \int_s \frac{\partial G}{\partial n} \bar{V}(\xi,\eta,\zeta) dS.$$

A fundamental property of the Green's function is that it is a symmetric function of the points (x, y, z); (ξ,η,ζ)—*i.e.*,

$$G(x,y,z\,;\ \xi,\eta,\zeta) = G(\xi,\eta,\zeta\,;\ x,y,z).$$

This means that the potential at P due to the charge induced over S by a unit charge at Q is equal to the potential at Q due to the charge induced over S by a unit charge at P. Helmholtz's reciprocal theorem in sound is also a consequence of this property of the Green's function. The solution of $\nabla^2 V + k^2 V$ which satisfies the boundary condition is given by solving the integral equation of the second kind.

$$V(x,y,z) = k^2 \iiint_s G(x,y,z\,;\ \xi,\eta,\zeta) V(\xi,\eta,\zeta) d\xi d\eta d\zeta,$$

and the Green's function for the equation $\nabla^2 V + k^2 V = 0$ is the solving function of the non-homogeneous integral equation. The properties of Green's functions in two dimensions are exactly analogous to those of Green's function in one dimension, except that condition (1) is replaced by the condition that

$$G - \log \sqrt{(x-\xi)^2 + (y-\eta)^2}$$

must be a regular analytic function in the neighbourhood of the point (ξ, η).

The Green's function has been determined for the circle, sphere, circular disc,[1] spherical bowl,[2] cone,[3] box [4] and wedge.[5]

The idea of a one-dimensional Green's function was introduced by Burkhardt [6] in (1894), and has been developed by Hilbert and his followers.[7]

The Green's function for a linear differential equation of order n is a

[1-2] E. W. Hobson, *Cambr. Phil. Trans.*; Stokes Commemoration Vol. (1899–1900), p. 277.

[3] Mehler, see Heine's *Theorie der Kugelfunctionen*, vol. ii., pp. 217–250. Also H. M. Macdonald, *Camb. Phil. Trans.*; Stokes Commemoration Volume, p. 292.; J. Dougall, *Proc. Edinburgh Math. Soc.* (1900).

[4] A. Daunderer, *Zeitschr. für Math. u. Phys.* (1909), p. 293.

[5] H. M. Macdonald, *Proc. London Math. Soc.*, vol. xxvi., p. 161 (1895); A. Sommerfeld, *ibid.* (1897).

[6] *Bull. Soc. Math.*, Bd. 22, 1894; See also papers by Dunkel, *Bull. Amer. Math. Soc.*, 1902; Bôcher, *ibid.*, 1901.

[7] *Gött. Nachr.*, 1904, and the dissertation by Mason (1903); Westfall (1905), *Annals of Math.*, 2nd ser., vol. x. No. 4. An application to systems of differential equation is made by Bounitzky. Liouville's *Journal*, t. 5, 1909, Fasc. 1, p. 65.

function $G(x,\xi)$ which satisfies certain boundary conditions and whose $(n-1)^{th}$ derivative experiences a sudden change in value of magnitude -1 at the point $x = \xi$. In the case of a differential equation of the 2nd order, the Green's function can usually be expressed in the form [1]

$$G(x, \xi) = \begin{matrix} u(x)v(\xi) & \quad x \leq \xi. \\ u(\xi)v(x) & \quad x \geq \xi. \end{matrix} \qquad (2)$$

where $u(x)$ is a solution which satisfies the boundary condition at one end of an interval (a, b), $v(x)$ a solution which satisfies the boundary condition at the other end of the interval. If the linear differential equation is $L(u) = 0$, then a solution of

$$L(u) + f(x) = 0$$

which satisfies the same boundary condition as G and has a continuous second derivative is given by the formula

$$u(x) = \int_a^b G(x,\xi)f(\xi)d\xi$$

and conversely if $u(x)$ is given, a solution of this integral equation of the first kind is provided *uniquely* by the formula

$$f(x) = -L(u).$$

The solution of $L(u) + \lambda u = 0$ which satisfies the boundary conditions also satisfies the integral equation

$$f(x) = \lambda\int_a^b G(x,\xi)f(\xi)d\xi,$$

and this determines the possible values of λ.

If the differential equation is self adjoint, the Green's function is a symmetric function of x and ξ, and it often happens in virtue of the formula (2) that it is a *definite* function. It then follows from the theory of integral equations that the values of λ are all *positive*.

The question of the existence and nature of the different values of λ for differential equations of various types has been discussed very thoroughly by Mason who uses a method depending on the calculus of variations.[2]

Extensive applications of Green's functions to problems of mathematical physics have been made by Picard,[3] Hilbert, Mason, Plemelj, Boggio,[4] Lauricella,[5] Hadamard,[6] and many other writers. The literature on this subject is now very extensive, but a good idea of the different problems may be derived from the articles by Bôcher and

[1] See the papers by Hilbert and Kneser, *Math. Ann.*, Bd. 63. Many examples of Green's functions are given in these papers, and also in a work by A. Myller. *Diss. Göttingen*, 1906.

[2] *Trans. Amer. Math. Soc.*, 7, 1906, p. 337.

[3] Liouville's *Journal*, ser. 4, 1890, p. 145, ser. 5, 1906, p. 129; *Rend. Palermo*, 1906 and 1909; *Annales de l'École Normale*, 1908.

[4] *Rend. Lincei*, 1907, p. 248.

[5] *Annali di Matematici*, 1907, ser. 3, t. 14, p. 143; *Rend. Lincei*, 1908.

[6] *Mémoires de l'Institut*, 1909.

Sommerfeld in the 'Encyklöpadie der Mathematischen Wissenschaften' and Mason's lectures at the Newhaven Mathematical Colloquium.

The problem of the determination of periodic solutions of differential equations is also reducible to the solution of an integral equation and has been discussed by Mason,[1] Lalesco,[2] A. Myller,[3] and others.

9. *Fredholm's Method.*

The beautiful researches of Fredholm[4] and Hilbert[5] on the integral equation of the second kind have opened out a wide field of research which now occupies the attention of a great number of mathematicians. The Paris Academy recognised the value of Fredholm's contributions to science by awarding him the Poncelet prize in 1908.

In Fredholm's method the integral equation

$$\kappa(s,t) = \mathrm{K}(s,t) - \lambda\int_a^b \kappa(s,x)\mathrm{K}(x,t)dx$$

satisfied by the solving function is treated as the limit of a system of linear equations.[6] The ordinary solution of such a system as the ratio of two determinants now takes the form [7]

$$\mathrm{K}(s,t) = \frac{\mathrm{D}(\lambda\,;\,s,t)}{\mathrm{D}(\lambda)},$$

where $\mathrm{D}(\lambda\,;\,s,t)$, $\mathrm{D}(\lambda)$ are the *integral functions* of λ defined by the equations

$$\mathrm{D}(\lambda\,;\,s,t) = \kappa(s,t) - \frac{\lambda}{1!}\int_a^b \kappa\begin{pmatrix} s & x_1 \\ t & x_1 \end{pmatrix}dx_1 + \frac{\lambda^2}{2!}\int_a^b\int_a^b \kappa\begin{pmatrix} s & x_1 & x_2 \\ t & x_1 & x_2 \end{pmatrix}dx_1\,dx_2 \,\ldots$$

$$\mathrm{D}(\lambda) = 1 - \frac{\lambda}{1!}\int_a^b \kappa\begin{pmatrix} x_1 \\ x_1 \end{pmatrix}dx_1 + \frac{\lambda^2}{2!}\int_a^b\int_a^b \kappa\begin{pmatrix} x_1 & x_2 \\ x_1 & x_2 \end{pmatrix}dx_1\,dx_2 \,\ldots,$$

and $\kappa\begin{pmatrix} x_1, & x_2 & \ldots & x_n \\ y_1, & y_2 & \ldots & y_n \end{pmatrix}$ is used to denote the determinant

$$\begin{vmatrix} \kappa(x_1,\,y_1) & \kappa(x_2,\,y_1) & \cdot & \cdot & \kappa(x_n,\,y_1) \\ \kappa(x_1,\,y_2) & \kappa(x_2,\,y_2) & \cdot & \cdot & \kappa(x_n,\,y_2) \\ \kappa(x_1,\,y_n) & \cdot & \cdot & \cdot & \kappa(x_n,\,y_n) \end{vmatrix}$$

[1] Liouville's *Journal*, 1904; *Trans. Amer. Math. Soc.*, 6, 1905, p. 159.

[2] *Comptes rendus*, 1907.

[3] *Ibid.*, 1907, p. 790.

[4] C. R. Stockholm, *Academy*, 1900, vol. lvii. p. 39; *Comptes rendus* (Paris), 1902, pp. 219, 1561; *Acta Math.*, vol. xxvii., 1903. Fredholm has recently issued a short report on the development and present state of the theory of integral equations (*Compte rendu du Congrès des Mathématiciens tenu à Stockholm*, 1909). I have not yet had the opportunity of consulting this.

[5] *Gött. Nachrichten*, 1904, Hefte i.–iii.; 1906, Hefte ii.–v. The method was described by Hilbert in Seminar and in lectures at Göttingen, 1900–01. His work is quite independent of that of Fredholm.

[6] This method of treatment is carried out in detail by Hilbert. See also Plemelj, *Monatshefte für Math.*, 1904. The fundamental idea was also used by Volterra, *Rend. Lincei*, 1884.

[7] The relation between this solution and the one obtained by Neumann's method is discussed by Kellogg (*Gött. Nachr.*, 1902), Plemelj and Poincaré (*Acta Math.*, 1909).

When $\kappa(s,t)$ is a bounded function, the convergence of the series may be established by means of a theorem in determinants due to Hadamard[1] which states that if A, $\bar{A}$ denote two determinants $[a_{ik}]$, $[\bar{a}_{ik}]$ whose constituents a_{ik}, $\bar{a}_{ik}$ are conjugate complex quantities such that $|a_{rk}| < \rho$ then

$$A\ \bar{A} \leq n^n\ \rho^{2n}$$

If the constituents are all real the maximum value of the determinant when $\sum_r a^2_{rk} = 1$ occurs when the quantities a_{rk} are the elements of an orthogonal matrix.

The case in which $\kappa(s,t)$ becomes infinite for $s = t$ like $\frac{1}{(s-t)^\alpha}$ has been considered by Fredholm, Hilbert, Korn,[2] Lalesco,[3] Goursat,[4] and Poincaré.[5] Fredholm shows that the integral equation

$$f(s) = \phi(s) - \lambda \int_a^b \kappa(s,t)\phi(t)dt$$

may be replaced by another one in which the kernel is the n^{th} iterated function and n may be chosen so that this function is bounded. Hilbert shows that if $\alpha < \frac{1}{2}$, Fredholm's series may be used provided the function $k(s, s)$ is replaced by zero wherever it occurs. This result has been extended by Poincaré and Lalesco to the case in which $\alpha > \frac{1}{2}$. Instead of deriving $D(\lambda)$ from Fredholm's expansion

$$\frac{D'(\lambda)}{D(\lambda)} = -\int_a^b \kappa(s,s)ds - \lambda\int_a^b \kappa_2(s,s)ds \quad . \quad . \quad .$$

$$- \lambda^{n-1}\int_a^b \kappa_n(s,s)ds \quad . \quad . \quad .$$

a function $\bar{D}(\lambda)$ is used such that $\frac{\bar{D}'(\lambda)}{\bar{D}(\lambda)}$ is equivalent to the above expansion when a suitable number of terms have been omitted. The new representation of $K(s,t)$ is of the form

$$K(s,t) = \frac{D(\lambda;\ s,t)}{D(\lambda)}.$$

The case in which the kernel is such that

$$\int_a^b /\kappa(s,t)/dt$$

exists and is uniformly convergent is considered by Levi.[6]

[1] *Bull. des Sciences Mathématiques*, 1893, 2nd ser., Bd. 17. Simplified proofs have been given by Hilbert (*Lectures on the Calculus of Variations*); Winter Semester (Göttingen, 1904–05); Wirtinger (*Monatshefte für Math. und Physik*, 1907, vol. xviii., p. 158); Fischer (*Grunert's Archiv*, 1908, p. 32).

[2] *Comptes rendus*, 1907.

[3] *Ibid.*

[4] *Ann. de Toulouse*, 1908.

[5] *Acta Math.*, 1909, t. 33, pp. 57–86.

[6] *Rend. Lincei*, 1907, 2nd sem. p. 604.

Plemelj, Lalesco, and Goursat also investigate the order of the integral functions $D(\lambda)$, $K(\lambda\,;\,s,\,t)$ and the latter obtains an expression for the determinant of an iterated kernel in terms of the determinant of the original one. If the function $\kappa(s,\,t)$ is bounded the order of $D(\lambda)$ is at most equal to two, but this is not the case if $\kappa(s,\,t)$ is not bounded. The necessary and sufficient condition that the determinant $D(\lambda)$ should have no roots is that

$$\int_a^b\int_a^b \kappa_n(s,t)dsdt = 0 \quad . \quad n > 1.$$

If λ is not a root of $D(\lambda) = 0$ the two adjoint integral equations

$$f(s) = \phi(s) - \lambda\int^b \kappa(s,t)\phi(t)dt$$

$$g(t) = \chi(t) - \lambda\int \chi(s)\kappa(s,t)ds$$

are solved uniquely by the formulæ

$$\phi(s) = f(s) + \lambda\int_a^b K(s,t)f(t)dt$$

$$\chi(t) = g(t) + \lambda\int_a^b g(s)K(s,t)ds,$$

and we have the reciprocal formula

$$\int_a^b f(s)\,\chi(s)ds = \int_a \phi(s)g(s)ds,$$

also
$$\frac{\partial\phi(s)}{\partial\lambda} = \int_a^b K(s,t)\,\phi(t)dt.$$

It should be noticed that the solving functions for two adjoint integral equations are the same and their determinants are also the same. The determinants are also the same for the functions [1]

$$\kappa(s,t) = \int_a^b f(s,x)g(x,t)dx$$

$$h(s,t) = \int g(s,x)\,f(x,t)dx,$$

and for the functions $\quad \kappa(s,t)\,;\ \kappa(s,t)\,\dfrac{f(t)}{f(x)}\,;$

[1] See a paper by the author, *Camb. Phil. Trans.*, 1906, vol. xx

while if two functions $\kappa(s,t)$, $h(s,t)$ are connected by a relation of the type

$$\int_a^b \kappa(s,x)f(x,t)dx \equiv \int_a^b f(s,x)h(x,t)dx$$

and no continuous functions exist such that

$$\int_a^b \alpha(x)f(x,t)dx = 0 \qquad \int_a^b f(s,x)\beta(x)dx = 0$$

then the determinants for the two kernels $k(s,t)$, $h(s,t)$ have the same roots.

If λ_n is a root of the determinantal equation $D(\lambda)=0$, then the homogeneous equations

$$\phi_n(s) = \lambda_n\int_a^b \kappa(s, t)\ \phi_n(t)dt$$

$$\chi_n(t) = \lambda_n\int_a^b \chi_n(s)\ \kappa(s,t)ds$$

can be satisfied by continuous functions $\phi_n(s)$, $\chi_n(t)$ which are not identically zero.

Conversely, if one of these equations can be satisfied by a continuous function, then λ_n is a root [1] of the determinant $D(\lambda)$ and it follows that the other equation also possesses a solution.

The roots of the determinant $D(\lambda) = 0$ are called the roots (Eigenwerte) of the kernel $\kappa(s,t)$ and the aggregate of these roots the *spectrum* of the kernel for the interval (a, b).

The functions or sets of functions $\phi_n(s)$, $\chi_n(t)$ which satisfy the homogeneous equation are called the *principal functions* associated with the root λ_n. If

$$\int_a^b \phi_n(s)\chi_n(s)ds \neq 0$$

we can say that $\phi_n(s)$ is *adjoint* to $\chi_n(s)$.

When the kernel is a symmetric function of s and t the functions $\phi_n(s)$, $\chi_n(s)$ become the same and form an orthogonal system of functions when the different values of λ_n are considered. They may then be called *normal* functions of the integral equation, the German equivalent being *Eigenfunktion*.

If λ_n is a simple root of $D(\lambda) = 0$, the only solutions of the above equations are constant multiples of $\phi_n(s)$, $\chi_n(t)$, and the solving function $K(s,t)$ has the form

$$K(s,t) = \frac{\phi_n(s)\chi_n(t)}{\lambda_n - \lambda} + F(s,t)$$

where $F(s, t)$ is finite for $\lambda = \lambda_n$.

[1] These theorems are due to Fredholm. A new proof of the last result has been given recently by Sorrel, *Bull. Amer. Math. Soc.*, vol. xv. (1909), p. 449. Further properties of the homogeneous equation are given in a paper by *Schur*. *Math. Ann.* Bd. 67 (1909), p. 306.

It follows from this result that a solution of the equation

$$f(s) = \phi(s) - \lambda\int_a^b \kappa(s,t)\phi(t)dt$$

becomes infinite when $\lambda = \lambda_n$, unless

$$\int_a^b f(t)\chi_n(t)dt = 0.$$

If this condition is satisfied the equation possesses a finite solution when $\lambda = \lambda_n$, but this solution is not unique since any constant multiple of $\phi_n(s)$ may be added to it. Plemelj [1] has obtained an expression for the principal part of the solving function in the vicinity of a value of λ, which is a multiple root of the determinant. The most important case is when the roots are all simple poles of $K(s,t)$, for then $K(s,t)$ has the form

$$K(s,t) = \frac{1}{\lambda_n - \lambda}\sum_m \phi_{n(s)}^{(m)}\chi_n^{(m)}(t) + F(s,t)$$

and the functions $\phi_n^{(m)}(s)$, $\chi_n^{(m)}(t)$ satisfy the equation

$$\int_a^b \phi_n^{(m)}(s)\chi_n^{(r)}(s)ds \begin{cases} = 0 & m \neq r \\ = 1 & m = r. \end{cases}$$

If $\phi_n(s)$, $\chi_l(t)$ are functions associated with two different roots λ_n, λ_l, we have

$$\int_a^b \phi_n(s)\chi_l(s)ds = 0.$$

The roots of the determinant $D(\lambda) = 0$ are all real, and are *simple poles* of the solving function, when $\kappa(s,t)$ is a symmetric function [2] of s and t, and also [3] when a definite function $g(s,t)$ can be found, so that

$$\int_a^b g(s,x)\kappa(x,t)dx = h(s,t)$$

is a symmetric function of s and t. The integral equations derived from the two potential problems belong to the second class. It should be noticed that a homogeneous integral equation of this class can be replaced by a homogeneous integral equation of the first kind

[1] *Monatshefte für Math. in Physik*, 1904. Other methods of obtaining the same result are given by Mercer, *Camb. Phil. Trans.*, vol. xxi., pp. 129–142, and A. C. Dixon, *ibid.*, vol. xix., part 2, p. 203; *Proc. Lond. Math. Soc.*, ser. 2, vol. vii., p. 314. See also papers by Bryon Heywood (Liouville's *Journal*, 1908) and Goursat (*Toulouse Ann.*, 1908). In obtaining his canonical form Plemelj introduces the idea of an integral congruence. This theory has been further developed by Landsberg (*Math. Ann.*, 1910, Bd. lxix. p. 227).

[2] Hilbert and Plemelj. A simple proof of this result is given by T. Boggio, *Comptes rendus* (1907).

[3] *Mess. of Math.* (1908), p. 8. See also J. Marty, *Comptes rendus* (Paris), Feb. 28 and April 25 (1910); Mrs. Pell, *Bull. Amer. Math. Soc.*, vol. xvi., July (1910).

$$\int_a [g(s,t) - \lambda h(s,t)]\phi(t)dt = 0$$

with symmetrical kernels $g(s,t)$, $h(s,t)$.

If the kernel is symmetric or belongs to the class just mentioned, it can be shown that there is at least one root of the determinant $D(\lambda) = 0$, and consequently at least one solution of the homogeneous equations. Also if the equation

$$\int \kappa(s,t)\beta(t)dt = 0, \qquad \int_a \alpha(s)\kappa(s,t)ds = 0,$$

only possess a finite number of linearly independent solutions, there are generally an infinite number of roots of the determinant $D(\lambda) = 0$.

If the kernel $\kappa(s,t)$ is a symmetric function of s and t the above theorems can be proved in a simple way by considering the energy function of the integral equation

$$f(s) = \phi(s) - \lambda\int_a^b \kappa(s,t)\phi(t)dt.$$

This function $w(\lambda)$ is defined by the equation

$$w(\lambda) = \int_a^b f(s)\phi(s)ds$$

and is such that

$$\frac{d}{d\lambda}\Big[\lambda w(\lambda)\Big] = \int_a^b \Big[\phi(s)\Big]^2 ds.$$

It follows from this equation that $\lambda w(\lambda)$ increases continually with λ. It generally becomes infinite at a value λ_n which is a root of the determinant $D(\lambda)$, an exception arising when the function $\phi(s)$ does not become infinite there. It should be noticed that although $\phi(s)$ is indeterminate as far as the addition of an arbitrary multiple of the function $\phi_n(s)$ corresponding to the root λ_n is concerned, yet $w(\lambda)$ has a unique value on account of the equations

$$\int_a^b f(s)\phi_n(s)ds = 0,$$

which express the conditions that $\phi(s)$ is finite. The energy function may be used for the following purposes :—

1° To find limits for

$$\frac{\int_a^b\int_a^b \kappa(s,t)\alpha(s)\alpha(t)dsdt}{\int_a [\alpha(s)]^2 ds} = \frac{1}{\lambda_0}.$$

Put

$$f(s) = \alpha(s) - \lambda \int_a^b \kappa(s,t)\alpha(t)dt$$

and consider the equation

$$f(s) = \phi(s) - \lambda \int_a^b \kappa(s,t)\phi(t)dt.$$

If λ_o is not a root of the determinant of this equation it follows that $\alpha(s)$ is the value of $\phi(s)$ for $\lambda = \lambda_o$, and so from the definition of λ_o the energy function $\lambda w(\lambda)$ associated with this equation vanishes for $\lambda = \lambda_o$. But it also vanishes for $\lambda = 0$ and increases continually with λ, hence there is at least one value between 0 and λ for which $w(\lambda)$ and consequently $\phi(s)$ becomes infinite. If λ_- and λ_+ are the numerically smallest negative and positive roots of $D(\lambda)$ we must have the inequalities

$$\frac{1}{\lambda_-} < \frac{1}{\lambda_o} \leq \frac{1}{\lambda_+}$$

This gives limits for the double integral and reduces to a theorem of Hilbert's in the case when $\kappa(s,t)$ is a definite function and the roots of $D(\lambda)$ consequently all positive. The theorem then takes the form of a problem in the calculus of variations of determining the maximum value of a double integral, the maximum value being provided by a function which satisfies the homogeneous integral equation.

It is clear that another pair of roots may be used in the inequality instead of λ_- and λ_+, if it is known that $\alpha(s)$ and consequently $f(s)$ satisfies the conditions of type

$$\int_a^b \alpha(s)\phi_n(s)ds = 0,$$

which make $\phi(s)$ finite for $\lambda = \lambda_-$ and $\lambda = \lambda_+$.

The above derivation of inequalities for the double integral establishes the existence of at least one root of the determinant $D(\lambda)$. The existence theorem is proved by Schmidt and Kneser by showing that the series for $\dfrac{D'(\lambda)}{D(\lambda)}$ has a finite radius of convergence. Schmidt also gives a method of obtaining a solution of the homogeneous integral equation by a limiting process, his proof being modelled on a classical one due to Schwarz.

2° Hilbert and Schmidt have given a theorem that if

$$\int_a^b \alpha(s)\phi_n(s)ds = 0$$

for all the functions $\phi_n(s)$ which satisfy the homogeneous integral equation

$$\phi_n(s) - \lambda_n \int_a^b \kappa(s,t)\phi_n(t)dt = 0$$

for the different values of λ_n, $\kappa(s,t)$ being a symmetric function, then

$$\psi(s) = \int_a^b \kappa(s,t)\alpha(t)dt = 0.$$

This theorem may be proved by reasoning with the double integral

$$\int_a^b\int_a^b \kappa_2(s,t)\alpha(s)\alpha(t)dsdt = \int_a^b [\psi(s)]^2 ds$$

in the same way as was done with the double integral with $k(s,t)$ as kernel instead of $\kappa_2(s,t)$. It is clear from the supposition made with regard to $\alpha(s)$, that if

$$f(s) = \alpha(s) - \lambda_o \int_a^b \kappa_2(s,t)\alpha(t)dt$$

where

$$0 = \int_a^b [\alpha(s)]^2 ds - \lambda_o \int_a^b [\psi(s)]^2 ds$$

then the energy function of the integral equation

$$f(s) = \phi(s) - \lambda \int_a^b \kappa_2(s,t)\phi(t)dt$$

never becomes infinite. But $\lambda w(\lambda)$ vanishes when $\lambda = 0$ and $\lambda = \lambda_o$ and increases continually with λ. Hence we come to a contradiction unless $\psi(s) \equiv 0$. The theorem is proved in another way by Schmidt.

It follows from this theorem that if no continuous function $\alpha(t)$ exists for which

$$\int_a^b \kappa(s,t)\alpha(t)dt = 0,$$

then there must be an infinite number of functions $\phi_n(s)$, and consequently an infinite number of roots λ_n of the determinant $D(\lambda)$. This is certainly the case, for instance, if $\kappa(s,t)$ is a definite function. These theorems are due to Hilbert.

An analogous set of theorems hold for the integral equation of the first kind [1]

$$f(s) = \int_a [g(s,\, t) - \lambda h(s,\, t)]\phi(t)dt, \quad . \quad . \quad . \quad (1)$$

where $g(s,t)$ is definite and $h(s,t)$ symmetrical.

The energy function is defined as before by the equation

$$w(\lambda) = \int_a f(s)\phi(s)ds.$$

Most of the properties belong to the integral equation of the second kind from which the homogeneous equation of type (1) is derived.

[1] *Mess. Math.*

The properties of the orthogonal system of functions associated with an integral equation of the second kind with symmetrical kernel are considered very fully by Schmidt. He shows how a complete set of orthogonal functions for the integral equation may be constructed, and obtains the important expansion

$$\phi(s) = f(s) + \lambda \Sigma \frac{\phi_n(s)}{\lambda_n - \lambda} \int_a^b f(s)\phi_n(s)ds$$

for the solution of the equation

$$f(s) = \phi(s) - \lambda \int_a^b \kappa(s,t)\phi_n(t)dt.$$

It is easy to derive from this expansion the conditions that a solution may remain finite in the vicinity of a root λ_n.

Schmidt has defined normal functions for an unsymmetrical kernel $\kappa(s,t)$ by means of the equations

$$\overline{\phi}_n(s) = \int_a^b \kappa(s,t)\overline{\chi}_n(t)dt,$$

$$\overline{\chi}_n(t) = \lambda \int_a^b \overline{\phi}_n(s)\kappa(s,t)ds,$$

and has obtained many theorems which are analogous to those proved for symmetrical kernels; for instance, the roots λ are all positive and there is an expansion theorem. The functions $\overline{\phi}_n(s)$, $\overline{\chi}_n(t)$ are respectively normal functions of the symmetric kernels of positive type,

$$\int_a^b \kappa(s,t)\kappa(x,t)dt, \qquad \int_a^b \kappa(x,s)\kappa(x,t)dx.$$

There are a number of interesting cases in which the solving function and determinant for one kernel may be derived from those of another. Bryon Heywood and Goursat show that if

$$\kappa(s,t) = \kappa_1(s,t) + \kappa_2(s,t),$$

where

$$\int_a^b \kappa_1(s,x)\kappa_2(x,t)dx = \int_a^b \kappa_2(s,x)\kappa_1(x,t)dx = 0,$$

then

$$D(\lambda) = D_1(\lambda)D_2(\lambda),$$

and

$$K(s,t) = K_1(s,t) + K_2(s,t).$$

This result is important in the discussion of the principal part of the solving function in the vicinity of a multiple root.

It has been shown by the author and by E. Schmidt, that when

$$\kappa(s,t) = h(s,t) + \sum_1^n f_n(s)g_n(t),$$

the solving function and determinant of $\kappa(s,t)$ may be calculated by means

of those belonging to $h(s,t)$. The case in which $h(s,t) = 0$ has been worked out by Goursat [1] and has been extended to infinite values of n by Lebesgue.[2]

In one interesting case the result can be expressed in a very concise form. If in Fredholm's notation

$$g(s,t) = \frac{\kappa\begin{pmatrix} s\, s_1\, s_2 \ldots s_n \\ t\, t_1\, t_2 \ldots t_n \end{pmatrix}}{\kappa\begin{pmatrix} s_1\, s_2 \ldots s_n \\ t_1\, t_2 \ldots t_n \end{pmatrix}}$$

then the solving function $G(s,t)$ and the determinant $\Delta(\lambda)$ for the kernel $g(s, t)$ are given by the formulæ

$$G(s,t) = \frac{K\begin{pmatrix} s\, s_1\, s_2 \ldots s_n \\ t\, t_1\, t_2 \ldots t_n \end{pmatrix}}{K\begin{pmatrix} s_1\, s_2 \ldots s_n \\ t_1\, t_2 \ldots t_n \end{pmatrix}}$$

$$\Delta(\lambda) = \frac{D(\lambda)K\begin{pmatrix} s_1\, s_2 \ldots s_n \\ t_1\, t_2 \ldots t_n \end{pmatrix}}{\kappa\begin{pmatrix} s_1\, s_2 \ldots s_n \\ t_1\, t_2 \ldots t_n \end{pmatrix}}$$

The function $D(\lambda)K\begin{pmatrix} s_1 s_2 \ldots s_n \\ t_1 t_2 \ldots t_n \end{pmatrix} = D\begin{pmatrix} \lambda ; & s_1 s_2 \ldots s_n \\ & t_1 t_2 \ldots t_n \end{pmatrix}$ is called an n^{th} minor of the determinant $D(\lambda)$ and is of great importance in the study of multiple roots of the determinant.

If we apply the formula

$$\int_a^b K(s_1 s)ds = -\frac{D'(\lambda)}{D(\lambda)}$$

to the function $G(s,t)$ we obtain the important formula

$$\int_a^b D\begin{pmatrix} \lambda ; & x\, s_1 s_2 \ldots s_n \\ & x\, t_1 t_2 \ldots t_n \end{pmatrix} dx = -\frac{d}{d\lambda} D\begin{pmatrix} \lambda ; & s_1 s_2 \ldots s_n \\ & t_1 t_2 \ldots t_n \end{pmatrix}.$$

The function $D\begin{pmatrix} \lambda ; & s \\ & t \end{pmatrix}$ is, of course, identical with $D(\lambda ; s,t)$ occurring in Fredholm's formula

$$K(s,t) = \frac{D(\lambda ; s,t)}{D(\lambda)}.$$

When $\lambda = \lambda_n$ is a multiple root of the determinant $D(\lambda)$, it is a minor of type

$$D\begin{pmatrix} \lambda_n ; & s, s_1, s_2 \ldots s_m \\ & t_o, t_1, t_2 \ldots t_m \end{pmatrix}$$

which is a solution of the homogeneous integral equation, but the order m of the minor is not necessarily equal to the multiplicity of the root. The properties of these minors are fully worked out by Fredholm and Plemelj. The latter shows that if the solving function has a pole of order

[1] *Bull. de la Soc. Math. de France*, 1907. [2] *Ibid.*, 1908.

i at the point $\lambda = \lambda_n$ and this root is of multiplicity p, then we have the inequalities

$$n \leq p - (i-1) \leq p$$
$$i > 1$$

The solving function is thus certainly infinite for $\lambda = \lambda_n$.

For further properties of the determinants and the solutions of the homogeneous equations, the reader is referred to the papers of Fredholm, Plemelj, Bryon Heywood, Goursat, Mercer and Dixon, and the following books, Kowalewski's 'Determinants,' Horn's 'Partial Differential Equations.'

Fredholm has invented an ingenious device by means of which a system of integral equations

$$f_r(s) = \phi_r(s) - \lambda \sum_{m=1}^{n} \kappa_{r,m}(s,t)\phi_m(t)dt \qquad (r = 1, 2 \ldots n)$$

may be replaced by a single integral equation.

We define

$$f(s) = f_r(s - r + 1) \qquad r - 1 \leq s < r$$
$$\phi(t) = \phi_r(t - r + 1) \qquad r - 1 \leq t \leq r$$
$$\kappa(s,t) = \kappa_{r,m}(s - r + 1, t - m + 1) \quad \left.\begin{matrix} r - 1 \leq s < r \\ m - 1 \leq t < m \end{matrix}\right\}$$

The system of equations may then be written in the form

$$f(s) = \phi(s) - \lambda\int_a^b \kappa(s,t)\phi(t)dt.$$

A similar artifice may be applied to a system of integral equations of the first kind.

The theory of systems of integral equations and equations in which there is more than one unknown function has been developed by Cauchy,[1] Murphy,[2] Volterra,[3] A. C. Dixon,[4] Bounitzky,[5] and Cotton.[6] The latter considers a system of integral equations in connection with a system of linear differential equations of the first order; while Bounitzky develops the theory of Green's functions for systems of differential equations.

Fredholm's method can easily be extended to integral equations involving surface and volume integrals. It is convenient to adopt Plemelj's notation and write $f(p)$ for a function of the parameters specifying the position of a point P. The whole of the present work then applies without much modification. It is, however, important to notice that in two dimensional problems, kernels which become infinite, like

$$\log\left\{\frac{1}{[(x-x^1)^2 + (y-y^1)^2]}\right\}$$

are certainly admissible as the iterated kernel is bounded. Also in three dimensional problems a kernel which becomes infinite like

[1] *Mémoire sur la théorie des Ondes*, 1815.
[2] *Cambr. Phil. Trans.*, 1833, vols. iv. and v.
[3] *Annali di Matematici*, 1897.
[4] *Ibid.*, vol. xix., part 2, p. 203.
[5] *Darboux's Bull.*, 1907 (2), t. 31; Liouville's *Journal*, 1909, t. 3.
[6] *Bull. de la Soc. Math. de France*, 1910, t. 38, fasc. 1-2.

$$\frac{1}{[(x-x')^2+(y-y')^2+(z-z')^2]^{\frac{1}{2}}}$$

can be used as an iterated kernel is bounded.

Additional Results.

Volterra's integral equation may be deduced from that of Fredholm by writing

$$\begin{aligned} \kappa(s,t) &= g(s,t) \qquad & t \leq s \\ &= 0 & t > s. \end{aligned} \qquad \text{(Fredholm)}$$

In the case of Hilbert's kernel

$$\begin{aligned} \kappa(s,t) &= s(1-t) \qquad & \leq t \\ & \quad t(1-s) & t \leq s \end{aligned}$$

the roots are π^2, $(2\pi)^2$, $(3\pi)^2$, and the normal functions

$$\sqrt{2}\sin(n\pi s).$$

If $r(x)$ is continuous in the interval (a,b) and does not vanish, the solving function for the kernel

$$g(x,t) = \frac{r(x)}{r(t)}\,\kappa(x,t)$$

is

$$\mathrm{G}(x,t) = \frac{r(x)}{r(t)}\,\mathrm{K}(x,t). \qquad \text{(Goursat)}$$

An integral equation with a kernel of form $r(x)g(x,t)$ where $g(x,t)$ is symmetric can be reduced to the symmetric form by multiplying throughout by

$$\sqrt{\frac{g(t)}{g(x)}}\,. \qquad \text{(Schmidt and Goursat)}$$

If $\kappa(s,t) = -\kappa(t,s)$, the roots are all purely imaginary quantities, but there are at least two.

10. *The Applications of Fredholm's Method to Potential Problems.*

The theory of the boundary problems of potential theory from the point of view of Fredholm's work has been worked out very fully by Fredholm, Hilbert, Kellogg,[1] Andrae,[2] Plemelj,[3] Picard,[4] and Lauricella.[5] Plemelj's papers contain almost an exhaustive discussion of the problems. We have seen that the theory depends upon the properties of the two adjoint integral equations

$$f(t) = \mu(t) - \lambda\int\mu(s)h(s,t)ds$$

$$f(t) = \rho(t) - \lambda\int h(t,s)\rho(s)ds,$$

[1] *Dissertation Göttingen*, 1902; *Math. Ann.*, 1903, Bd. lviii.; 1904, Bd. lx.
[2] *Dissertation Göttingen*, 1903.
[3] *Monatshefte für Math. in Phys.*, 1904 and 1906.
[4] *Rend. Palermo*, 1906. See also *Comptes rendus*, 1905–08.
[5] *Il Nuovo Cimento*, 1907, ser. 5, vol. xiii.

and the discussion of these depends upon the properties that

$$\int h(s,\sigma)ds = 1$$

for a regular point of the boundary, and that the kernel

$$\kappa(\sigma,\tau) = \int h(s,\sigma)g(s,\tau)ds$$

is a *symmetric* function of σ and τ while $g(s,\tau)$ is *definite*.

The first result indicates that the homogeneous integral equation

$$\psi(t) = \lambda\int\psi(s)h(s,t)ds \quad . \quad . \quad . \quad . \quad (1)$$

may be satisfied for $\lambda = 1$ by $\psi(s) = 1$, hence the equation for $\rho(t)$ or the internal hydrodynamical problem does not possess a finite solution unless

$$\int f(t)dt = 0.$$

It follows also that the homogeneous equation

$$\phi(s) = \int h(s,t)\phi(t)dt \quad . \quad . \quad . \quad . \quad (2)$$

also possesses a solution, and so the equation for $\mu(t)$ or the external electrostatic problem does not possess a solution unless a condition of the type

$$\int\phi(s)f(s)ds = 0$$

is satisfied.

It may be shown by use of a theorem relating to the behaviour of the normal derivative of the potential of a double layer[1] that the homogeneous integral equations do not possess solutions for the case $\lambda = -1$ if the boundary consists of a single closed surface. This proves that the integral equations possess unique solutions for the case $\lambda = -1$, and so the internal problem of Dirichlet and the external hydrodynamical problems possess unique solutions.

Plemelj and Lauricella have shown that the fundamental problem of electrostatics of determining a potential of a simple layer which is such that it is constant over the boundary and

$$\int\rho(s)ds = \mathrm{M}$$

has a given value, is solved by means of the function $\phi(s)$; for the function

$$\int g(s,\tau)\phi(s)ds = \psi(\tau)$$

[1] Careful examinations of the question have been given by Plemelj and Lauricella. A simplified exposition due to Darboux is given in d'Adhémar's book *L'équation du Fredholm et les problèmes de Dirichlet et de Neumann*, 1909 (Paris).

satisfies the equation

$$\psi(\tau) = \iint g(s,\tau)h(s,t)\phi(t)dsdt$$

$$= \iint h(s,\tau)g(s,t)\phi(t)dsdt$$

on account of the symmetry of $\kappa(\tau,t)$

and so $$\psi(\tau) = \iint h(s,\tau)\psi(s)ds.$$

Hence since it can be shown that $\lambda = 1$ is only a simple root for the integral equation the function $\psi(s)$ must be a constant, and so the potential of a simple layer having $\phi(s)$ as density is constant over the boundary.

Lauricella and Picard have also considered the problem of determining a potential of a double layer which shall coincide with a potential of a simple layer in one of the regions of space. The problem depends on a double application of the preceding problems and provides a method of solving a type of integral equation of the first kind.

Plemelj has shown further how one can proceed to determine the Green's function, and he introduces a more general type of Green's function and discusses its properties.

Plemelj's discussion of the potential problems is not confined to a single closed surface; he considers a boundary consisting of a number of closed surfaces, some of which surround a number of others. In the general case both $\lambda = -1$ and $\lambda = +1$ are roots of the kernel $h(s,t)$, and are in fact multiple roots. It follows however from the symmetry of $k(s,t)$ that the solving function has only *simple* poles which are all *real*. The theory is considerably simplified by this circumstance. The solutions of the homogeneous equation analogous to (2) provide the densities of potential functions which are constant over one surface and zero over all the others.

Plemelj has also applied the theory to more general electrostatic problems in which surfaces of discontinuity of the potential are considered.

The modifications introduced into the discussion of the problems when the boundary has corners or conical points are considered by Kellogg. He shows that in the case of a curve with a sharp angle ω at $s = 0$,

$$h(t,s) = -\frac{\sin\omega}{\pi}\,\frac{s}{s^2 - 2st\cos\omega + t^2} + E_1(s,t) \qquad \begin{matrix} s < 0 \\ t > 0 \end{matrix}$$

$$= \frac{\sin\omega}{\pi}\,\frac{s}{s^1 - 2st\cos\omega + t^2} + E_2(s,t) \qquad \begin{matrix} s > 0 \\ t < 0 \end{matrix}$$

where $E_1(s,t)$ $E_2(s,t)$ are finite for $s = t = 0$. The case of a cusp is exceptional.

For such a kernel $h(t,s)$ the series for $D(\lambda\,;\,s,t)$ and $D(\lambda)$ in Fredholm's theory are meaningless since $h(s,t)$ becomes infinite to too high an order. This is certainly the case, for instance, when ω is a right angle.

11. *Orthogonal and Biorthogonal Systems of Functions.*

A set of functions $\psi_n(s)$ is said to form an orthogonal system belonging to the interval $(a \leq s \leq b)$ when the relations

$$\int_a^b \psi_m(s)\psi_n(s)ds \begin{cases} = 0 & m \neq n \\ = 1 & m = n \end{cases}$$

are satisfied for the different integral values of the suffixes m,n. The system is said to be closed relative to a field of functions M when no function belonging to this field exists such that

$$\int^b f(s)\psi_n(s)ds = 0$$

or all the values of n.

Particular systems of orthogonal functions are the trigonometrical functions $\cos ns$, $\sin ns$ (Clairaut, Euler, Lagrange, Fourier) and Legendre's polynomials $P_n(\mu)$. Jacobi indicated the importance of orthogonal functions in mechanical integration, and the study of these functions was taken up by Murphy.[1]

Murphy introduced the idea of biorthogonal systems of functions, *i.e.*, systems of functions $\phi_m(s)$, $\chi_n(s)$ which are connected by the equations

$$\int_a^b \phi_n(s)\chi_n(s)ds \begin{cases} = 0 & m \neq n \\ = 1 & m = n \end{cases}$$

he called $\phi_m(s)$ and $\chi_m(s)$ *reciprocal* functions. It is more convenient now to call them *adjoint* functions, as they are generally solutions of pairs of adjoint integral equations or adjoint differential equations.

A biorthogonal system of functions may be constructed from an orthogonal system by writing

$$\phi_m(s) = \Sigma\, a_{mn}\psi_n(s)$$
$$\psi_n(s) = \Sigma\, a_{mn}\chi_m(s)$$

where $a_{mn} = 0$ if $n > m$ (Murphy).

An orthogonal system of functions for an interval (a,b) is not unique for we may derive a new set from a given one by an orthogonal substitution (change of rectangular axes)

$$\psi_m(s) = \Sigma l_{mn}\psi_n(s)$$

where

$$\sum_n l_{mn}l_{pn} = 0 \qquad \sum_n l_{mn}^2 = 1$$

or by writing

$$\phi_m(s) = \int_a^b \kappa(s,t)\psi_m(t)$$

$$\psi_n(t) = \int_a^b \chi_n(s)\kappa(s,t)ds$$

[1] *Camb. Phil. Trans.*, 1833, vols. iv.–v.

for then
$$\int_a^b \phi_m(s)\chi_n(s)ds = \int_a^b \psi_n(t)\psi_m(t)dt.$$

A method of deriving a large class of orthogonal and biorthogonal systems of functions from a single integral equation has been given by the author.[1]

J. P. Gram [2] and E. Schmidt [3] have given a method of constructing an orthogonal system of functions from a linearly independent set of functions $a_n(s)$. It is assumed that
$$\begin{aligned}\psi_1(s) &= \lambda_{11}a_1(s)\\ \psi_2(s) &= \lambda_{21}a_1(s) + \lambda_{22}a_2(s)\\ \psi_3(s) &= \lambda_{31}a_1(s) + \lambda_{32}a_2(s) + \lambda_{33}a_3(s)\end{aligned}$$
and the constants λ_{pq} are chosen so that the functions $\psi_n(s)$ form an orthogonal system.

It has already been noticed that orthogonal and biorthogonal systems of functions occur as the solutions of linear differential and integral equations; they also occur in certain problems of the calculus of variations, for instance, the problem of finding sets of functions $\phi_n(s)$ $\psi_n(t)$, so that
$$\int_a^b\int_a^b \left[\kappa(s,t) - \sum_{\nu=1}^{m} \frac{\phi_\nu(s)\psi_\nu(t)}{\lambda_\nu}\right]^2 dsdt$$
may be a minimum (Schmidt).

The best known examples of orthogonal sets of functions are the following :—

If $\frac{s^{1-\frac{h}{h}}}{1-h} = \sum_{n=0}^{\infty} h^n\psi_n(s)$, then the functions $\psi_n(s)$ are orthogonal for the interval $o \leq s \leq 1$ (Abel [4] and Murphy [5]).

If
$$Q_p(s) = e^{2s}\frac{d^p}{ds^p}(e^{-2s}s^p)$$
denotes the polynomial of Laguerre,[6] the functions
$$\psi_n(s) = \sqrt{2}\,\frac{e^{-s}Q_n(s)}{n!}$$
form an orthogonal system for the interval $(o < s < \infty)$.

If
$$P_p(s) = (-1)^p e^{\frac{1}{2}s^2}\frac{d^p}{ds^p}(e^{-\frac{1}{2}s^2})$$
denotes the polynomial introduced by Tschebyscheff [7] and Hermite,[8] the functions
$$\psi_n(s) = \frac{e^{-(\frac{s}{2})^2}P_n(s)}{\sqrt[4]{2\pi}\,.\,\sqrt{n!}}$$

[1] *Camb. Phil. Trans.*, vol xx. (1907), p. 281. [2] *Crelle's Journal*, Bd. xciv.
[3] *Dissertation Göttingen*, 1905; *Math. Ann.*, 1907.
[4] *Mémoires de mathématiques*, par N. H. Abel (Paris, 1826), pp. 75–79.
[5] *Cambr. Phil. Trans.*, 1833.
[6] *Œuvres*, t. 1, p. 428. [7] *St. Petersburg Memoirs*, 1860.
[8] *Comptes rendus*, 1864, t. 58, pp. 93, 266.

form an orthogonal system for the interval $(-\infty, +\infty)$. The polynomials of Hermite and Laguerre have been studied in connection with integral equations by Wera Lebedeff[1] and Weyl.[2] Hermite's polynomials occur in solutions of the equation of the conduction of heat and also in solutions of the equation of the parabolic cylinder. Various definite integral representations of them have been obtained by Whittaker[3] and Watson.[4]

Another class of normal functions, called by K. Pearson the ω-functions, can be derived from the equation of the conduction of heat; they occur in the theory of statistics. The expansions in series of ω-functions have been discussed by E. Cunningham.[5]

In addition to the orthogonal functions mentioned above, there are the trigonometrical functions $\sin a_k x$ where the quantities a_k satisfy a transcendental equation,[6] the Bessel's functions $J_n(a_k x)$ under like conditions, and functions such as the Legendre polynomial, spherical harmonics, the functions associated with the equation of the elliptic cylinder, and Lamé's functions. Also there are functions such as

$$\frac{J_{n+\frac{1}{2}}(x)}{\sqrt{x}}$$

which form an orthogonal system for the unlimited interval $(-\infty, \infty)$.

12. *Expansions in Series of Orthogonal Functions.*

When a function $f(x)$ can be expanded in a series of the type

$$f(x) = \Sigma a_n \psi_n(x) \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

which is uniformly convergent in the interval for which the orthogonal functions are defined, then the coefficients may be determined by the so-called Fourier's rule

$$a_n = \int_a^b f(x)\psi_n(x)dx \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and similarly for expansions in series of functions belonging to biorthogonal system.

The Fourier's constants a_n may often be used to specify a function $f(x)$ even when the series for $f(x)$ is not convergent, and there is a remarkable theorem due to de la Vallée Poussin and Liapounoff for Fourier's series, which enables us to express the integral of the product of two functions $f(x)$, $g(x)$ in terms of their Fourier's constants. The formula is

$$\int_a f(x)g(x)dx = \Sigma\, a_n b_n,$$

[1] *Dissertation Göttingen*, 1906; *Math. Ann.*, Bd. lxiv, p. 400.
[2] *Dissertation Göttingen*, 1908.
[3] *Proc. Lond. Math. Soc.*, vol. xxxv. (1903), p. 417.
[4] *Ibid.*, 1910, vol. viii.
[5] *Proc. Roy. Soc. A.*, vol. lxxxi. (1908), p. 310.
[6] Various expansions of this type are considered by A. Stephenson, *Mess. of Math.*, p. 1 (1903), April (1904), and the author, *Camb. Phil. Trans.*, vol. xx., p. 281.

and in particular

$$\int_a^b [f(x)]^2 dx = \Sigma a_n^2.$$

Riesz[1] has shown that this theorem holds if $f(x)$ and $[f(x)]^2$ are summable or integrable in the interval (a,b) and the system of orthogonal functions $\psi_n(x)$ is complete. The converse theorem is also true. If Σa_n^2 converges, then a function $f(x)$ which is summable and whose square is also summable, exists such that the integral equation (2) is satisfied. This theorem has been proved by Riesz,[1] Fischer,[2] Hellinger,[3] and Weyl,[4] and forms the basis of the method by which Picard[5] has obtained necessary and sufficient conditions that the integral equation

$$f(x) = \int_a^b \kappa(x,t)\phi(t)dt$$

may possess a solution $\phi(t)$ which is summable and whose square is also summable in the interval (a,b).

In the treatment of series of orthogonal functions $\psi_n(\xi)$ the following identity which Schmidt attributes to Bessel[6] is of fundamental importance:—

$$\int_a^b [f(x) - \sum_{i=1} \psi_i(x) \int_a^b f(\xi)\psi_i(\xi)d\xi]^2 dx$$

$$= \int_a^b [f(\xi)]^2 d\xi - \sum_{i=1}^{n} \left(\int_a^b f(\xi)\psi_i(\xi)d\xi\right)^2$$

This gives rise to the inequality

$$\int_a^b [f(\xi)^2 d\xi \geq \sum_{i=1}^{n} \left(\int_a^b f(\xi)\psi_i(\xi)d\xi\right)^2$$

which reduces to Schwarz's inequality when $n = 1$.

13. *Expansions in Series of Orthogonal Functions connected with a Linear Differential or Integral Equation.*

The theory of these expansions now forms quite a large branch of mathematics, as will be seen from Burkhardt's excellent report on expansion in series of oscillating functions. Since the appearance of this work

[1] *Comptes rendus*, 1907; *Göttinger Nachrichten*, 1907.
[2] *Comptes rendus*, 1907. [3] *Dissertation Göttingen*, 1907.
[4] *Math. Ann.*, Bd. lxxix., 1909.
[5] *Comptes rendus*, 1909, t. 148; *Rend. Palermo*, 1909.
[6] *Astr. Nach.*, 1828, vol. vi., p. 333. Bôcher points out that Bessel considers sums instead of integrals, and refers to Plarr, *Comptes rendus*, 1857, vol. xliv., p. 985.

new ground has been broken by Dixon,[1] Kneser,[2] Stekloff,[3] Hilbert,[4] Schmidt,[5] Mason,[6] Hobson,[7] and Filon.[8]

In Hilbert's expansion theorem a function which can be expressed in the form

$$f(x) = \int_a^b G(x,t)\phi(t)dt. \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $G(x,t)$ is a *symmetrical kernel* and $\phi(t)$ a *continuous* function, can be expanded in an absolutely and uniformly convergent series of the form

$$f(x) = \sum_{n=1}^{\infty} a_n\psi_n(x)$$

where the functions $\psi_n(x)$ are a complete system of orthogonal functions derived from the kernel $G(x,t)$. By taking $G(x,t)$ as the Green's function of a linear differential equation the expansion theorem for series of solutions of the differential equation is obtained, and the condition (1) may be usually replaced by the condition that $f(x)$ possesses a continuous second derivative and satisfies the boundary conditions.

By means of this theorem all the known expansion theorems—*e.g.*, in series of Bessel, Sturm, Legendre and Lamé's functions and also those discussed by Poincaré—the normal functions of the differential equation

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} + \lambda u = 0$$

investigated by Le Roy, Stekloff, Zaremba, Korn, and others, are made to depend upon the properties of an integral equation of the type

$$f(s) = \phi(s) - \lambda\int_a^b \kappa(s,t)\phi(t)dt$$

where

$$\int_a^b \int_a^b [\kappa(s,t)]^2 ds dt$$

has a finite value.

A simplified proof of Hilbert's theorem was given by Schmidt and a restriction was removed. Schmidt also extended the theorem by introducing two systems of orthogonal functions $\phi_n(s)$, $\psi_n(t)$ connected with an unsymmetrical kernel. These functions are defined by the equations

$$\phi_n(s) = \lambda_n\int_a^b \kappa(s,t)\psi_n(t)dt$$

$$\psi_n(t) = \int_a^b \phi_n(s)\ \kappa(s,t)ds$$

[1] *Proc. London Math. Soc.*, ser. 2, vol. iii.
[2] *Math. Ann.*, vols. lviii., lx., lxiii.
[3] *Annales de Toulouse*, 2nd ser., t. 3; *Comptes rendus*, April 8, 1907.
[4] *Göttinger Nachrichten*, 1904.
[5] *Dissertation Göttingen*, 1905; *Math. Ann.*, 1907, vol. lxiii.
[6] *Trans. Amer. Math. Soc.*, 1907, vol. viii., p. 427.
[7] *Proc. London Math. Soc.*, ser. 2, vol. vi., p. 349 (1908).
[8] *Ibid.*, ser. 2, vol. iv., p. 396 (1906).

and are evidently the orthogonal functions derived from the symmetrical kernels

$$G(s,x) = \int_a^b \kappa(s,t)\kappa(x,t)dt$$

$$H(s,x) = \int_a^b \kappa(z,s)\kappa(z,x)dz$$

The roots λ_n are all positive since $G(s,x)$, $H(s,x)$ are kernels of *positive type*, and are the same for both $G(s,x)$ and $H(s,x)$. These orthogonal functions $\phi_n(s)$, $\psi_n(t)$ are used by Picard in finding the conditions that the equation

$$f(x) = \int_a^b \kappa(x,t)\phi(t)dt$$

may be soluble, and many other theorems connected with an integral equation of the first kind may be expressed in terms of them.

Hilbert's expansion theorem does not, however, apply to the important case in which the function $f(x)$ has singularities or is discontinuous. The work of Dixon, Kneser, and Hobson remedies this deficiency. Kneser considers series of the Sturm-Liouville type, and removes the restrictions imposed by Stekloff and Hilbert, that the function be continuous with its first and second derivatives, and satisfy the same boundary conditions as the normal functions.[1] Hobson has carried the theory a step further by introducing Lebesgue integrals, and considering the case in which the function has singularities. He obtains a very general convergence theorem and applies it also to series of Legendre and Bessel's functions. Dixon considers the very important class of harmonic expansions of the type

$$\kappa(x,t) = \Sigma\, a_n\phi_n(x)\,\psi_n(t)\,;$$

his paper contains many interesting results.

Recent work on the subject has also been done by Birkhoff[2] and Mercer.[3]

Dixon and Filon discuss the expansion by means of Cauchy's theory of residues; the work is interesting, and seems to suggest that Cauchy's method may be of value in the treatment of integral equations if we consider contour integrals in which the determinant $D(\lambda)$ appears in the denominator.

Various other expansion theorems connected with integral equations have been considered by the author, but for these we must refer to the original papers.

14. *Integral Equations of the First Kind.*

An integral equation of the type

$$f(x) = \int_a^b \kappa(x,t)\phi(t)dt \quad . \quad . \quad . \quad . \quad . \quad (1)$$

[1] Mason removes a restriction imposed on the differential equation that one of the functions should be positive.

[2] *Amer. Trans.*, 1908, vol. ix., p. 373. [3] *Phil. Trans. A.*, 1910–11.

in which the limits of integration are *fixed* has been called by Hilbert [1] an integral equation of the first kind. The term 'integral equation' is due to P. Du Bois Reymond.[2]

The function $\kappa(x,t)$ is called the *kernel* (*kern*, Noyau), but the terms *nucleus*, *characteristic function* are sometimes used.

Particular forms of equation (1) were considered by Laplace, Fourier, and Abel, but a general theory was first given by Murphy,[3] who considered the equation in connection with electrostatical problems. It should be mentioned that some of the problems considered in Green's essay (Nottingham 1828) are equivalent to integral equations of the first kind.

It was pointed out by Peacock [4] that the homogeneous equation

$$o = \int_a^b \kappa(x,t)\chi(t)dt$$

may possess an infinite number of solutions, and it was observed by Murphy and Liouville that the general solution of (1) may be expressed as the sum of a complementary function and a particular integral. The integral equation (1) has been studied by Pincherle [5] in connection with the theory of distributive operations and by Pincherle,[6] Levi Civita,[7] and the author in connection with linear differential equations.

A useful method of solving the equation is to expand the function $\kappa(x,t)$ in a series of the form

$$\kappa(x,t) = \Sigma a_n \psi_n(x) \chi_n(t)$$

and the function $f(x)\phi(t)$ in the form

$$f(x) = \Sigma c_n \psi_n(x) \ldots .$$
$$\phi(t) = \Sigma b_n \phi_n(t)$$

where the functions $\phi_n(t), \chi_n(t)$ are connected by the relations

$$\int_a^b \phi_m(t)\chi_n(t)dt = 0. \qquad m \neq n.$$
$$= 1. \qquad m = n.$$

This method, which is virtually given by Murphy, has been developed in other forms by Dini,[8] Lauricella,[9] Picard,[10] and the author.[11] Picard has made use of a theorem due to Riesz on expansions in series of orthogonal functions to obtain an expression for the necessary and sufficient conditions that a function $f(x)$ may be capable of being expressed in the form (1). The condition is that a certain series of constants derived from the function $f(x)$ should converge. It is necessary of course to impose a number of restrictions upon the function $\kappa(x,t)$.

[1] *Göttinger Nachrichten*, 1904. [2] *Crelle*, 1888, vol. ciii., p. 228.
[3] *Cambr. Phil. Trans.*, 1833, vol. v., pp. 113–148, 315–394.
[4] *Brit. Assoc. Report*, 1833. [5] *Acta Math.*, 1887.
[6] *Acta Math.*, 1892; *Chicago Congress*, 1892. [7] *Lomb. Rend.*, 1895 Torino Atti, 1895.
[8] *Ann. Univ. Tosc.*, 1880, vol. xvii. Dini's method really applies to an equation of Volterra's type.
[9] *Rend. Lincei*, 1908, p. 193. [10] *Rend. Palermo*, 1910.
[11] *Proc. London Math. Soc.*, 1907, ser. 2, vol. iv., p. 461; *Mess. Math.*, 1910, p. 129.

In some cases the equation (1) possesses a unique solution $\phi(t)$ of a *specified* type. If $\phi(t)$ is continuous, this is the case for instance if the double integral

$$\int_a^b\int_a^b \kappa(x,t)\phi(x)\phi(t)dxdt$$

is positive for every continuous function ϕ. A kernel $\kappa(x,t)$ which is symmetrical and possesses this property is said to be *definite* (Hilbert). The same definition appears to hold if

$$\int_a^b \phi(t)dt \qquad \text{and} \qquad \int_a^b [\phi(t)]^2 dt$$

exist.

When the solution of an integral equation can be expressed by means of a single formula, *e.g.*,

$$\phi(t) = \int_0^\infty F(t,x)f(x)dx$$

this formula is called an inversion formula. A large number of inversion formulæ for different types of integrals are known.

The integral equation (1) and the homogeneous equation (2) may be studied as limiting cases of the integral equations of the second kind—

$$f(x) = \mu\phi(x) + \int_a^b \kappa(x,t)\phi(t)dt$$

$$\mu\phi(x) + \int_a^b \kappa(x,t)\phi(t)dt = 0$$

when $\mu = 0$. This method was suggested by Fredholm and has been developed by the author.[1]

Many properties of the integral equation are suggested when it is considered as the limit of a system of linear algebraic equations. There are indications of this idea in the work of Fourier and Murphy. The method was used by Volterra in 1884 and has formed the basis of the epoch-making work of Fredholm and Hilbert in the theory of the integral equation of the second kind. At present the most powerful method of solving integral equations of the first kind is to express the kernel as a definite integral of a convenient type and solve the equation in two steps. The formulæ of Fourier, Hankel, and Pincherle and the multiplication theorem of section 16 are of fundamental importance in this connection.

15. *Canonical Form of an Integral Equation of the First Kind. Definite Functions.*

An integral equation of the type

$$f(x) = \int_a^b \kappa(x,t)\phi(t)dt$$

[1] *Mess. Math.*, April (1910).

is reduced to a canonical form by multiplying it by $p(x)\kappa(x,s)$, where $p(x)$ is a *positive* function and integrating[1] between suitable limits a',b'. If

$$h(s) = \int_{a'}^{b'} f(x)p(x)\kappa(x,s)dx,$$

$$g(s,t) = \int_{a'}^{b'} p(x)\kappa(x,s)\kappa(x,t)dx,$$

the new equation is

$$h(s) = \int_a^b g(s,t)\phi(t)dt.$$

The new kernel $g(s,t)$ is a *symmetric* function of s and t and is such that the double integral

$$\int_a^b\int_a^b g(s,t)\chi(s)\chi(t)dsdt$$

is either positive or zero for any arbitrary continuous function $\chi(t)$, or in fact for any summable function whose square is also summable. Such a kernel is said to be of *positive type*.[2] A function $g(s,t)$ which is such that the double integral is always *positive* is called a *definite* function (Hilbert); this, of course, is an extension of the idea of a definite quadratic form.

The sum of a definite function and a set of functions of positive type is clearly a definite function; this fact and the above method of constructing functions of positive type enable us to form many types of definite functions.

It has been shown by the author and by J. Mercer that if $a(x)$ is a real continuous function which is never negative and never decreases as x increases from a to b, then the function $g(x,t)$ defined by the equation

$$\begin{aligned} g(x,t) &= a(t) \quad a \leq t \leq x \leq b \\ &= a(x) \quad a \leq x \leq t \leq b \end{aligned}$$

is a definite function. From this it follows that if $\beta(x)$ $\gamma(x)$ are continuous functions which are never negative, and if $\gamma(x)$ increases with x and $\beta(x)$ at the same time decreases, then the function

$$\begin{aligned} h(x,t) &= \beta(t)\gamma(x) \qquad x \leq t \\ &= \beta(x)\gamma(t) \qquad x \geq t \end{aligned}$$

is definite.[3] The functions $\beta(t)$, $\gamma(t)$ may vanish at the upper and lower limit respectively.

[1] If $f(x)$ is only known for a countable set of values of x, we must sum instead of integrating. If, however, Lebesgue integrals are used the distinction is unnecessary.

[2] This nomenclature is due to Mercer, *Phil. Trans. A.*, vol. ccix., pp. 415-416.

[3] The conditions are satisfied for Hilbert's function

$$h(x,t) = \begin{matrix} x(1-t) \\ t(1-x) \end{matrix} \cdot \begin{matrix} x \leq t \\ x \geq t \end{matrix}$$

The case in which $\beta(x)$ and $\gamma(x)$ are solutions of a differential equation is of special interest, for then $h(x,t)$ is generally a Green's function (section 8). The conditions in which two solutions of the differential equation exhibit the required properties are indicated by the following theorem due to Dixon, Weyl, and Kneser.

Let

$$L(u) \equiv \frac{d}{ds}\left[p(s)\frac{du}{ds}\right] - q(s)u = 0$$

be a linear differential equation in which $p(s)$ is a positive function having a continuous first derivative for $s \geq 0$, while $q(s)$ is continuous for all positive values of s and such that

$$q(s) \geq 0.$$

Let $\gamma(s)$ be a solution of $L(u) = 0$ defined by the initial conditions

$$\gamma(o), \quad p(o)\gamma'(o) = 1;$$

then

$$\frac{d\gamma}{ds} > 0, \quad \gamma(s) > 0, \quad \text{for } s > 0.$$

Similarly, if $\beta(s)$ is a solution defined by the initial conditions

$$u(o) = 1, \quad u(1) = 0$$

we have

$$\frac{d\beta}{ds} < 0, \quad \beta \geq 0.$$

Hence the solutions $\beta(s)$, $\gamma(s)$ satisfy the above conditions.

It has been proved by Mercer (l.c.) that the necessary and sufficient conditions that a function $g(s,t)$ may be of positive type are that the quadratic form

$$\sum_p \sum_q g(p,q)x_p x_q$$

should be definite[1] for any choice of a set of points p,q . . . in the given interval. This theorem has been extended by W. H. Young.

It is clear that the properties of definite functions may be extended to functions of several variables. It is important to notice that the functions

$$\frac{1}{[(x-x)^2+(y-y^1)^2+(z-z^1)^2]^{\frac{1}{2}}} \quad \frac{1}{[(x+x^1)^2+(y-y^1)^2+(z-z^1)^2]^{\frac{1}{2}}}$$

in which the variables (x,y,z) (x^1,y^1,z^1) are the coordinates of points on a closed surface are *definite functions.*

The first function occurs in potential problems connected with a single closed surface, the second function occurs in potential problems connected with a closed surface in front of an infinite plane. This property of the functions depends on the identities

[1] The conditions are that the quantities $g(s_1 s)\, g\begin{pmatrix} s_1 s_2 \\ s_1 s_2 \end{pmatrix}, g\begin{pmatrix} s_1 s_2 s_3 \\ s_1 s_2 s_3 \end{pmatrix}$ . . . . should be positive for every set of values of the variables $s_1, s_2, s_3,$ . . . . contained in the interval (a,b).

$$\frac{1}{[(x-x^1)^2+(y-y^1)^2+(z-z^1)^2]^{\frac{1}{2}}} = \frac{1}{4\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}$$

$$\frac{(\xi-x)(\xi-x^1)+(\eta-y)(\eta-y^1)+(\zeta-z)(\zeta-z^1)}{[(\xi-x)^2+(\eta-y)^2+(\zeta-z)^2]^{\frac{3}{2}}[(\xi-x^1)^2+(\eta-y^1)^2+(\zeta-z^1)^2]^{\frac{3}{2}}}\,d\xi d\eta d\zeta$$

$$\frac{1}{[(x+x^1)^2+(y-y^1)^2+(z-z^1)^2]^{\frac{1}{2}}} = \frac{1}{\pi}\int_0^{\infty} da \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}$$

$$\frac{(x+a)(x^1+a)\,d\eta d\zeta}{[(x+a)^2+(\eta-y)^2+(\zeta-z)^2]^{\frac{3}{2}}[(x^1+a)^2+(\eta-y^1)^2+(\zeta-z^1)^2]},$$

the second of which is due to Lord Kelvin.

It also follows from the equation

$$\sqrt{\frac{\pi}{t}}\,e^{-\frac{(x-x^1)^2}{4t}} = \int_{-\infty}^{\infty} e^{-\frac{(\xi-x)^2+(\xi-x^1)^2}{2t}}\,\frac{d\xi}{t}$$

that for positive values of t the kernel on the left is definite for values of x and x^1 in any real interval.

Additional Results.

If a definite function $g(s,t)$ is such that $g(s,s)$ vanishes for one value of $s = s_o$, then $g(s_o,t)$ and $g(s,s_o)$ are zero for all values of t and s (Mercer).

16. *Multiplication Formulæ and their Applications.*

Borel has shown that if,

$$f(x) = \int_0^{\infty} e^{-xt}\phi(t)dt, \qquad g(x) = \int_0^{\infty} e^{-xt}\psi(t)dt. \quad . \quad . \quad (1)$$

then, with certain limitations,[1]

$$f(x)g(x) = \int_0^{\infty} e^{-xt}\chi(t)dt,$$

where

$$\chi(t) = \int_0^t \phi(t-\tau)\psi(\tau)d\tau.$$

This result is very useful for solving equations of the type

$$a(t) = \lambda\beta(t) + \mu\int_0 \kappa(t-\tau)\beta(\tau)d\tau,$$

for if we multiply by e^{-xt} and integrate between o and ∞ there is an algebraic relation between the functions derived from $a(t)$, $\beta(t)$, $\kappa(t)$ by formulæ of type (1).

[1] The theorem has been established under much less stringent conditions by Bromwich. *Infinite Series*, pp. 280–283.

It is clear that any multiplication theorem for integrals may be used in a similar way.

The multiplication theorems for integrals of the types

$$f(x) = \int_0^1 t^{x-1}\psi(t)dt \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$f(x) = \int_0^\infty t^{x-1}\phi(t)dt \quad . \quad . \quad . \quad . \quad . \quad (3)$$

have been given by Mellin.[1]

If $\phi_1(t)$, $\phi_2(t)$ are the functions corresponding to $f_1(x)$, $f_2(x)$, the function $\psi(t)$ corresponding to the product is given for integrals of type (2) by

$$\psi(t) = \int_t^1 \phi_1\left(\frac{t}{z}\right)\phi_2(z)\frac{dz}{z},$$

and for integrals of type (3) by

$$\psi(t) = \int_0^\infty \phi_1\left(\frac{t}{z}\right)\phi_2(z)\frac{dz}{z}.$$

There are also a number of multiplication theorems for Fourier's integrals. For instance, if

$$f(x) = \int_0^\infty \cos xt\phi(t)dt, \qquad g(x) = \int_0^\infty \cos xt\psi(t)dt$$

and $\phi(t)$ is an even function of t, then

$$f(x)g(x) = \int_0^\infty \cos xt\chi(t)dt,$$

where
$$\chi(t) = \tfrac{1}{2}\int_0^\infty [\phi(t-\tau) + \phi(t+\tau)]\psi(\tau)d\tau.$$

These theorems have not been thoroughly investigated.

Integral equations of the type

$$f(x) = \int_0 \kappa(x-\xi)\phi(\xi)d\xi$$

are of very frequent occurrence. The following hydrostatical problem may be taken as an example :—

A solid in the shape of a surface of revolution is immersed with its axis vertical in a heterogeneous fluid, and weights are placed on the top

[1] *Acta Societatis Fennicae*, 1896, t. 21, No. 6; *Math. Ann.*, Bd. 68, 1910. See also Bromwich's *Infinite Series.*

of the solid so that it sinks to a given depth. Find the law of density of the fluid in order that the total weight of the solid and weights may be a given function of the depth to which solid sinks.

17. *Integral Equations in which the Principal Value of the Integral must be taken.*

The inversion formulæ for integral equations in which the integral has its principal value are often very simple—for instance, Hilbert gave in his lectures the formula

$$\phi(s) = \int_0^1 f(t) \cos \pi(s - t)dt + \int_0^1 \phi(t)dt$$

$$f(s) = - \int_0 \phi(t) \cos \pi(s - t)dt + \int_0 f(t)dt$$

particular forms of which had been known for some time. This formula was used to solve more general equations of the first kind in which an integral has a principal value. The formulæ have been derived and extended also by Kellogg.[1]

A general theory of inversion formulæ connected with integrals of which the principal values must be taken,[2] has been given by Hardy [3] and many beautiful results have been obtained.

Integral equations of the type under consideration are of some importance in two dimensional potential problems, as they arise when the point at which the potential is estimated is taken on the attracting curve.

Additional Results.

If $\phi(x)$ and its first two derivatives are continuous and $|\phi(x)| < \kappa$, and the integrals

$$\int^{\infty} \frac{\phi(x) \log x}{x} dx, \int_{-\infty} \phi(x) \log (-x) \frac{dx}{x}$$

are convergent, and if

$$\pi\chi(y) = \mathrm{P}\int_{-\infty}^{\infty} \frac{\phi(x)dx}{x - y},$$

then

$$\pi\phi(y) = \mathrm{P}\int_{-\infty}^{\infty} \frac{\chi(x)dx}{y - x}. \qquad \text{(Hardy)}$$

Also if

$$\chi(y) = \mathrm{P}\int_0^1 \operatorname{cosec} \pi(x - y)\phi(x)dx,$$

[1] *Dissertation*, 1902.

[2] Stokes, *On the Highest Wave of Uniform Propagation*; *Proc. Cambr. Phil. Soc.*, 1883, vol. iv., pp. 361–365; *Math. and Phys. Papers*, vol. v., pp. 140–159. The Correspondence of Hermite and Stieltjes.

[3] *Proc. Lond. Math. Soc.*, 1909, ser. 2, vol. vii., p. 181.

then $$\phi(y) = \mathrm{P}\int_0^1 \operatorname{cosec} \pi(y-x)\chi(x)dx, \qquad \text{(Hardy)}$$

where P denotes that the principal value of the integral must be taken.

18. *Distributive Operations.*

It has been pointed out by Pincherle [1] that many of the theorems of integral equations are simply illustrations of theorems belonging to the general theory of distributive operations, and this is one of the leading ideas in the applications to integral equations of the General Analysis developed by E. H. Moore.[2]

Although the use of symbols to denote operations was first advocated by Leibnitz [3] and his calculus of symbols was developed by Lagrange,[4] the first great step in the theory was made by Servois [5] who showed that the analogies between the calculus of symbols and ordinary algebra depend on the fact that the various symbols Δ, $\frac{d}{dx}$, Σ, &c., possess the commutative, distributive, and associative properties; the first two terms were in fact introduced by Servois.

Two symbols A, B are said to obey the *commutative* law if

$$AB = BA,$$

they are said to obey the *associative* law if

$$A(BC) = (AB)C$$

where C is any other symbol of the same type.

If the symbols A,B denote operations it is convenient to interpret AB as the result of first operating with B and then with A. If the two operations obey the commutative law, the order in which they are performed is immaterial.

In order to define the distributive law we must introduce the idea of objects or functions on which the symbol or operation acts. If $\alpha, \beta \ldots .$ denote different objects, an operation A is said to be *distributive* when

$$A(\alpha + \beta + \ldots .) = A(\alpha) + A(\beta) + \ldots . \quad A(c\alpha) = cA(\alpha).$$

A set of functions which are chosen according to some law is called a *field* of functions, a function α is said to be a condensation function of the field when to every positive quantity ε there is a function β belonging to the field and different from α and such that

$$|\alpha - \beta| < \varepsilon.$$

A field which contains all its condensation functions is said to be

[1] *Rend. Lincei*, 1905; *Bologna Memoirs*, ser. 6ª, vol. iii. A good account of the theory of distributive operation is given in the book by Pincherle and Amaldi, *Le Operazioni Distributive*, Bologna (1901).

[2] Newhaven, *Mathematical Colloquium*; Yale Univ. Press, 1910.

[3] *Berol. Miscell.*, 1710, i. p. 160. 'The Correspondence of Leibnitz and John Bernoulli,' Leibnitz's *Mathematical Works* (1), iii., p. 175.

[4] *Œuvres*, 1772, t. 3, p. 441. [5] *Gergonne Ann.*, 1814, t. 5, p. 93.

closed. These definitions have been extended by E. Schmidt[1] to functions of an infinite set of variables.

A field of functions is said to be *linear* if, when α, β are any two functions belonging to the field, the function

$$\lambda\alpha + \mu\beta$$

also belongs to the field, λ and μ being arbitrary constants.

It often happens that by performing an operation A upon a function α of a field M another function β of the field is produced. When this is the case the functions for which the operation is periodic are of special interest, in particular if the operation is of period one so that

$$\alpha = \lambda A(\alpha)$$

where λ is a constant the function α is called an invariant of the operation A (Pincherle). Thus in the case of the operation defined by the definite integral

$$A(f) = \int_a^b \kappa(s,t)f(t)dt$$

the invariants ϕ satisfy integral equations of the type

$$\phi(s) = \lambda \int_a^b \kappa(s,t)\phi(t)dt.$$

If A and B are two operations the equation

$$AB\phi = BA\phi$$

is generally a functional equation which determines the functions ϕ with respect to which the operations A, B are commutative, but it may happen that it is satisfied identically. In the case of the operations

$$A(f) = \int_a^b \kappa(s,t)f(t)dt, \quad B(f) = \int_a^b h(s,t)f(t)dt$$

this is the case if[2]

$$\int_a^b \kappa(s,x)h(x,t)dx = \int_a^b h(s,x)\kappa(x,t)dx.$$

This equation is satisfied by series of the type

$$h(x,t) = \Sigma a_n\phi_n(x)\chi_n(t)$$

where $\phi_n(x)$, $\chi_n(t)$ satisfy the homogeneous integral equations

$$\mu_n\phi_n(s) = \int_a^b \kappa(s,x)\phi_n(x)dx$$

$$\mu_n\chi_n(t) = \int_a^b \chi_n(x)\kappa(x,t)dx.$$

[1] *Rend. Palermo*, 1907.

[2] Some properties of permutable functions are considered by Volterra, *Rend Lincei*, April 17, 1910.

Pincherle has made considerable use of a very suggestive analogy in which the functions of a field are compared with the points of a space of an enumerally infinite number of dimensions and distributive operations with linear transformations of this space into itself. The properties of adjoint operations are then indicated by the correlative properties of points and linear manifolds of order $n-1$ in a space of n dimensions. The use of a space of an enumerably infinite number of dimensions has been further developed by Fréchet[1] and Schmidt.[2]

In some cases the conditions that two operations

$$A(f),\ \bar{A}(\phi)$$

may be adjoint can be expressed in a very simple form such as

$$\int_a^b A(f)\phi(x)dx \equiv \int_a^b \bar{A}(\phi)f(x)dx$$

or

$$\phi A(f) - f\bar{A}(\phi) = \frac{d}{dx}(R),$$

the latter form occurring in the theory of linear differential equations. The other form shows that the operations

$$A(f) = \int_a \kappa(x,t)f(t)dt, \qquad \bar{A}(\phi) = \int_a^b \phi(s)\kappa(s,x)ds$$

are adjoint.

An important property of adjoint operations is that if one operation is composite, *e.g.*, $A = BC$, the adjoint operation is also composite, and consists of the adjoint factors in the reverse order, *i.e.*, $\bar{A} \equiv \bar{C}\bar{B}$.

In some cases an operation X can be inverted in a unique manner by an inverse operation X^{-1}. The discovery of the operation inverse to a given one depends on the solution of a functional equation: if the operation involves a definite integral the equation will be an integral equation. Since the operation inverse to a distributive operation is also a distributive operation, it is convenient to have a general expression for a distributive operation.

This has been supplied by Hadamard in the case of the particular class of distributive operations which are continuous; these are called *linear operations*. An operation is said to be continuous[3] in a field of functions M if, when $a(x)$, $a_1(x)$, $a_2(x)$ are a sequence of limited functions belonging to M, and such that

$$a_n(x) \rightarrow a(x) \text{ as } n \rightarrow \infty$$

except, perhaps, for a set of values of x whose content is zero, then

$$A(a) = \lim_{n \rightarrow \infty} A(a_n).$$

[1] *Rend. Palermo*, 1906. [2] *Ibid.*, 1907.

[3] Bourlet, *Annales de l'École Normale*, 1903, ser. 3, t. 14. See also Hadamard's paper.

Hadamard[1] has proved that any linear operation $A(\alpha)$ can be expressed in the form

$$A(\alpha) = \lim_{n \to \infty} \int_a^b K_n(x)\alpha(x)dx$$

where $K_n(x)$ is a suitably chosen function. This result is important because it indicates the general form to be expected for the inversion formula of a linear integral equation.

Fréchet[2] has given other proofs of Hadamard's theorem, and has shown that in particular the functions $K_n(x)$ may be taken to be polynomials.

The transformation of operations is also of some importance in the theory of integral and differential equations. Let X be an operation which can be inverted in a unique manner by means of an operation X^{-1}, then an operation A is said to be transformed in B by means of X when we have identically[3]

$$B = XAX^{-1}.$$

If A_1 is transformed into B_1 and A_2 into B_2, then A_1A_2 is transformed into B_1B_2. If the operations A form a group, the operations B also form a group. If two of the A's are permutable the corresponding B's are also permutable. If A is transformed into B the adjoint operation $\bar{B}$ is transformed into $\bar{A}$. These theorems find a good illustration in the connection between the transformations of Euler and Laplace in the theory of linear differential equations.

19. *Connection with the Calculus of Variations.*

A connection between integral equations and the calculus of variations was indicated by Volterra[4] in 1884. He showed that the integral equation

$$f(x) = \int_0^a \kappa(x,t)\phi(t)dt \qquad o \leq x \geq a$$

may be obtained by making the first variation of the quantity

$$P = \tfrac{1}{2}\int_0^a\int_0^a \kappa(x,t)\phi(x)\phi(t)dxdt - \int_0^a f(x)\phi(x)dx$$

equal to zero.

Hilbert obtained another connection by showing that the maximum value of the integral

$$\int_a^b\int_a^b \kappa(x,t)\phi(x)\phi(t)dxdt$$

[1] Hadamard, *Comptes rendus*, Feb. 9, 1903.

[2] *Trans. Amer. Math. Soc.*, 1905, vol. vi., No. 2, p. 138.

[3] Pincherle and Amaldi, Ch. 13. The theory was applied to continuous groups of transformations by C. Jordan. *Annali di Matematica*, 1868, ser. ii., t. 2.

[4] *Il nuovo Cimento*, 1884, series 3[A], vol. xvi., p. 49.

subject to the condition

$$\int_a^b [\phi(x)]^2 dx = 1$$

is $\frac{1}{\lambda_1}$ where λ_1 is the smallest value of λ for which the homogeneous integral equation

$$\phi(x) - \lambda \int_a^b \kappa(x,t)\phi(t)dt = 0$$

can be satisfied. The other roots $\lambda_2, \lambda_3, \ldots$ are obtained by finding the maximum value of the integral when a number of additional conditions of the type

$$\int_a^b \phi(t)\phi_r(t)dt$$

are introduced, $\phi_r(t)$ being solutions of the homogeneous equation for the roots λ_r.

Hilbert assumed in his investigation that $\kappa(x,t)$ was a definite function, so that all the quantities λ_r are positive. This restriction has been removed by the author,[1] who has found limits within which the double integral must lie; the method depends upon a use of the *energy function*. Another proof of Hilbert's theorem is given by Holmgren.[2]

There is an analogous theorem due to Dirichlet for differential equations, and this has been used by Mason[3] to establish the following general theorem:—

There exists an infinite series of normal parameter values λ_n and corresponding solutions (normal functions) y_n of the differential equation

$$y'' + \lambda A y = 0 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and the boundary conditions

$$y(a) = 0, \qquad y(b) = 0 \quad . \quad . \quad . \quad . \quad (2)$$

If A changes sign in (a,b) the values λ_n include an infinite series of positive terms $\lambda_1 < \lambda_2 < \lambda_3 < \ldots$, increasing without limit, and an infinite series of negative terms

$$\lambda_{-1} > \lambda_{-2} > \lambda_{-3} > \ldots$$

decreasing without limit. The function y_n satisfies the conditions

$$\int_a^b A y^2_n dx = \pm 1 \qquad \int_a^b A y_i y dx = 0$$
$$[i = \pm 1, \pm 2, \ldots \pm (n-1)]$$

(in which the upper or lower signs are to be taken according as n is positive or negative), and gives to the integral

[1] *Camb. Phil. Trans.*, 1908, vol. xxi.
[2] *Comptes rendus*, 1905.
[3] *Amer. Trans.*, 1906, vol. vii, p. 337.

$$J(y) = \int_a^b \left(\frac{dy}{dx}\right)^2 dx$$

its least possible value consistent with these conditions and the equations (2). This minimum value of J is $\pm \lambda_n$.

More general theorems have been deduced for the differential equation and more general boundary conditions.

These problems arise naturally in the Calculus of Variations in the following way [1]:—

Consider the problem of determining a curve $y = y(x)$ joining two given points for which the integral

$$J = \int_a F(y', y, x) dx$$

has a minimum value.

Let $\bar{y} = \bar{y}(x)$ be the equation of the required curve and

$$y = \bar{y} + \epsilon u$$

a neighbouring curve, where u is supposed to satisfy the following conditions:

(1) In the interval $a \leq x \leq b$, $u(x)$ possesses a continuous first derivative.

(2) u vanishes for $x = a$ and for $x = b$.

We then have

$$J = \int_a^b [F(\bar{y}', \bar{y}, x) + \epsilon(u'F_1 + uF_2)$$

$$+ \frac{\epsilon^2}{2}(u'^2F_{11} + 2u'uF_{12} + u^2F_{22}) + \quad . \quad . \quad]dx$$

$$= \bar{J} + \epsilon \int_a^b u\left(F_2 - \frac{dF_1}{dx}\right)dx$$

$$+ \frac{\epsilon^2}{2}\int_a^b \left[u'^2F_{11} - u^2\left(\frac{dF_{12}}{dx} - F_{22}\right)\right] dx +$$

where F_1, F_2, F_{11}, . . denote the partial derivatives of $F(\bar{y}', \bar{y}, x)$ with regard to $\bar{y}'$ $\bar{y}$.

Now since $\bar{y}$ makes J a minimum

$$F_2 - \frac{d}{dx}(F_1) = 0$$

and

$$u'^2F_{11} - u^2\left(\frac{dF_{12}}{dx} - F_{22}\right) \text{ is positive.}$$

Hilbert now considers the problem of determining the function $u(x)$ so that the quantity

$$\Omega = \int_a^b \left[u'^2F_{11} - u^2\left(\frac{dF_{12}}{dx} - F_{22}\right)\right] dx$$

[1] Hilbert, *Lectures on the Calculus of Variations*, Göttingen, 1904–05.

may be a minimum when $u(x)$ satisfies the condition

$$\int_a^b [u(x)]^2 dx = 1$$

which is introduced to exclude the case of $u(x) = 0$.

The linear differential equation corresponding to this isoperimetric problem is

$$L(u) + \lambda u = 0$$

where
$$L(u) = \frac{d}{dx}\left(F_{11}\frac{du}{dx}\right) + \left(\frac{dF_{12}}{dx} - F_{22}\right)u.$$

The function $u(x)$ must satisfy this equation and the conditions already laid down, and this can only be done for certain values of λ.

This theory is developed in the Göttingen dissertations of König (1907) and Cairns (1907). The latter considers a function which makes the integral Ω a minimum subject to the two conditions

$$\int_a^b u(x)g(x) = 0, \qquad \int_a^b u^2(x)dx = 1,$$

and arrives at a differential equation

$$L(u) + \lambda u + \lambda' g(x) = 0.$$

He shows that if $\Gamma(x,\xi)$ is the Green's function for the differential equation when $\lambda' = 0$, and

$$v(x) = \int_a^b \Gamma(x,\xi)g(\xi)d\xi,$$

then the Green's function in the case when λ is not zero is given by the formula

$$G(x,\xi) = \Gamma(x,\xi) - \frac{v(x)v(\xi)}{\int_a^b v(t)g(t)dt}.$$

This result is closely connected with a general theorem given by the author.[1]

König discusses Hilbert's problem in connection with Jacobi's criterion and the oscillation theorem.

A fuller investigation has been given recently by Richardson.[2]

20. *Riemann's Problem.*

The work of Fuchs raised the question as to how far the branch points and monodromic group belonging to a linear differential equation can be considered as independent of one another. Riemann endeavoured to answer this question in 1857 by considering the problem of determining

[1] *Cambr. Phil. Trans.*, 1907, vol. xx., pp. 281–290.
[2] *Math. Ann.*, 1910, Bd. lxviii., p. 279.

the differential equation when the branch points and group are known. The problem was solved by Schlesinger[1] with the aid of Poincaré's Zetafuchsian functions in the case when all the roots of the characteristic equations, which belong to the fundamental substitutions corresponding to the circuits round the singular points, have their moduli equal to unity. The convergence of the series of Zeta functions is then ensured. Schlesinger[2] has more recently used a method of continuity to obtain a proof of the solubility of Riemann's problem.

A new method of dealing with the problem was invented by Hilbert[3] in 1901. He considers first of all Riemann's general problem[4] of determining, in the interior of a region of the complex plane bounded by a given curve, C, functions of a complex variable when relations are given between the real and imaginary parts of the values which the functions assume on the boundary. Hilbert shows that if

$$f(z) = u(x,y) + iv(x,y)$$

and $u(s)$, $v(s)$ are the values which the functions u,v take on the boundary, then the problem of determining $f(z)$ when a relation of the type

$$a(s)u(s) + b(s)v(s) + c(s) = 0$$

is given, $a(s)$, $b(s)$, $c(s)$ being periodic functions of the arc s with continuous derivatives, can be reduced with the aid of a Green's function to the solution of an integral equation of the second kind.[5] He then goes on to show that the problem of determining a pair of functions $f_0(z), g_0(z)$ which are regular outside C and a pair of functions $f_1(z), g_1(z)$ which are regular inside C, so that there is a given linear transformation

$$f_0(s) = c_1(s)f_1(s) + c_2(s)g_1(s)$$
$$g_0(s) = e_1(s)f_1(s) + e_2(s)g_2(s)$$

with complex coefficients $c_1(s)$, $c_2(s)$, $e_1(s)$, $e_2(s)$, each of which possess a continuous second derivative, can be reduced by means of Green's functions to the solution of a pair of integral equations of the second kind, and these may be reduced to a single equation of the second kind by means of Fredholm's artifice.

These results are then applied to the solution of the problem of the monodromic group by formulating this problem in the following way: Let a closed analytic curve C be drawn so as to pass once through each of the singular points $z_1, z_2 \ldots . z_m$, then we have to find a pair of functions $f(z)$ $g(z)$ which shall behave like regular functions of the complex variable at all points of the plane, including the strip of C between z_m and z_1, but which shall exhibit a singular behaviour on the

[1] *Comptes rendus*, 1898, t. 126, p. 723–725; *Math. Ann.*, 63, pp. 273–276.

[2] *Crelle*, Bd. cxxx.; *Acta Math.*, Bd. xxxi.; *Ann. d'Éc. Norm. Sup.*, (3) 20, 1903.

[3] *Vorlesungen*, 1901–02; *Heidelberg Congress*, 1904; *Göttingen Nachr.*, 1905.

[4] Another treatment of this problem is given by A. C. Dixon, *Cambr. Phil. Trans.*, vol. xix., part 2, p. 203.

[5] Further investigations on this subject have been made by Haseman, *Dissertation Göttingen*, 1907.

portions of the curve between z_1 and z_2, z_2 and z_3 .... z_{m-1} and z_m. If
$f_0(z)$, $g_0(z)$ denote the values of $f(z)$ and $g(z)$ outside C,
$f_1(z)$, $g_1(z)$ „ „ „ inside C,

then the conditions to be satisfied are that

$$f_0 = f_1, \quad g_0 = g_1 \quad \text{on the portion } z_m z_1 \text{ of C}$$

$$\left.\begin{array}{l} f_0 = \gamma_1^{(h)} f_1 + \gamma_2^{(h)} g_1 \\ f_0 = \epsilon_1^{(h)} f_1 + \epsilon_2^{(h)} g_1 \end{array}\right. \text{ on the portion } z_h z_{h+1} \quad (h = 1, 2, \ldots m).$$

Plemelj [1] has shown that this problem of Riemann may be solved in a much simpler way by using Cauchy's integral formula in place of Green's functions.

Hilbert also gives sufficient conditions that a given complex expression

$$u(s) + iv(s)$$

may be the boundary value on C of a function of a complex variable which is regular inside or outside C.

21. *The Solution of Linear Differential Equations by means of Definite Integrals.*[2]

Laplace's method of solving linear differential equations by means of definite integrals has been extended by Heine, Pincherle, Jordan, Pochhammer, Schlesinger, and many other writers. The general method of solving an equation $L_x(u) = 0$ by means of a definite integral of the type

$$f(x) = \int \kappa(x,t)\phi(t)dt$$

depends upon the formation of an identity of the form

$$L_x(\kappa) \equiv M_t(w)$$

where $w(x,t)$ may or may not be identical with κ. If $\bar{M}_t(v) = 0$ is the differential equation adjoint to $M_t(w) = 0$ we have in general

$$L_x(f) = \int L_x(\kappa)\phi(t)dt = \int M_t(w)\phi(t)dt = \int \frac{d}{dt} R + \int w(x,t)\bar{M}_t(\phi)dt$$

where R is the bilinear concomitant. The first integral can usually be made to vanish by a suitable choice of the limits, and the second integral vanishes if $\phi(t)$ is a solution of the equation

$$\bar{M}_t(v) = 0$$

which is called the transformed equation relative to the kernel κ. In the case when $\kappa(x,t) = e^{xt}$ we may take $w(x,t) = e^{xt}$, and then if

[1] *Sitzungsberichte*, Vienna, May 10, 1906; *Monatshefte für Mathematik und Physik* 1908; *Jahresbericht der deutschen Math. Verein.*, 1909, p. 15.

[2] A report and bibliography on the theory of linear differential equations from 1865–1907 is given by Schlesinger, *Jahresbericht der deutschen Math. Verein.*, 1909, pp. 133–266.

$$L_x(u) = \Sigma a_{mn} x^m \frac{d^n u}{dx^n}$$

$$M_t(v) = \Sigma a_{mn} t^n \frac{d^m v}{dt^m}.$$

The equation $M_t(v) = 0$ is then the Laplace transformed equation.

It was shown by Petzval [1] in 1859 that Laplace's transformation is periodic, the second transformation yielding the original equation except for a change of sign of the independent variable. This, of course, was indicated by Fourier's integral formula. The result is important, as it indicates the existence of inversion formulæ of the type

$$f(x) = \int_0^\infty e^{-xt}\phi(t)dt, \qquad \phi(t) = \frac{1}{2\pi i}\int_c e^{xt}f(x)dx.$$

These formulæ have been studied by Pincherle.[2] A particular inversion formula

$$f(z) = \frac{1}{2\pi}\int_0^\infty \phi(v)e^{v(z-k)}dv, \quad \phi(v) = \int_{-\infty}^\infty f(k+is)e^{-ivs}\,ds$$

$$z = x + iy$$
$$x < k$$

was given by Cauchy [3] long ago.

The general theory of periodic transformations has been developed by Pincherle [4] and Levi Civita.[5] Those in which the original differential equation is reproduced after a single transformation are of special interest, as they connect themselves naturally with homogeneous integral equations of the type

$$\phi(s) = \lambda\int_a^b \kappa(s,t)\phi(t)dt.$$

An important class of equations which are transformed into themselves by a transformation of Laplace has been discovered by M. Abraham,[6] and has been extended by the author.[7] The equation of the elliptic cylinder belongs to this class of equations.

The transformation in which the kernel is of the form

$$(x - t)^{\nu - 1}$$

is of special interest, and is called after *Euler*, since he first used integrals of the type

$$\int_a^b (x - t)^{\nu-1}\,\phi(t)dt$$

to solve linear differential equations. The theory of the transformation has been developed chiefly by Heine, Pincherle, Schlesinger, Jordan

[1] *Integration der linearen Differentialgleichungen*, pp. 472–473. Simple derivations of Petzval's result have been given by Pincherle (*Le operazioni distributive*, Bologna, 1901) and the author, *Proc. Lond. Math. Soc.*, 1907, ser. 2, vol. iv., p. 487.

[2] *Bologna Memoirs*, ser. 4, t. 7–8, 1886–87; ser. 6, 1907, vol. iii., p. 143.

[3] *Comptes rendus*, Paris, 1851, t. 32, p. 215.

[4] *Acta Math.*, 1892, t. 16.

[5] *Torino Atti*, 1895, t. 31; *Lomb. Rend.*, 1895, t. 28.

[6] *Math. Ann.*, 1901, Bd. lii., p. 81.

[7] *Cambr. Phil. Trans.*, 1909.

and Pochhammer. The last two authors have enriched the theory by the introduction of double circuit integrals.

Pincherle[1] has obtained a symbolic expression for Euler's transformation E_ν in terms of Laplace's transformation L and the operation M_n of multiplying the dependent variable by x^n. This formula

$$E_\nu = L^{-1} M_{-\nu} L$$

suggests the existence of inversion formulæ of the type

$$f(x) = \int (x-t)^{\nu-1} \phi(t)dt$$

$$\phi(t) = \lambda \int (x-t)^{-\nu-1} f(x)dx$$

where λ is some constant.

The equation

$$f(s) = \int_{-1}^{+1} \frac{\phi(t)dt}{(1-2ts+s^2)^\nu} \qquad \nu > 0$$

$$\phi(s) = \frac{(1-s^2)^{\nu-\frac{1}{2}}}{\pi} \int^{\pi} [\nu f(x) + xf^1(x)] \sin^{2\nu-} \alpha d\alpha$$

where $x = s + i\sqrt{1-s^2} \cos \alpha$ provides an interesting example.

Abel's integral equation is a particular case of a formula of this kind. Other formulæ have been considered by Pincherle[2] and the author.[3]

The transformations associated with kernels of the forms $\kappa(x-t)$, $\kappa(xt)$ have been discussed by Mellin.[4] These transformations may be conveniently studied in connection with the multiplication formulæ. Transformations of other types have been considered by Picard and Cunningham, but at present these seem to belong to the theory of differential equations rather than that of integral equations.

Transformations of difference equations into differential equations lead to integrals involving Gamma Functions. These integrals were discovered by Pincherle,[5] and have been studied subsequently by Mellin[6] and Barnes.[7] The theory of these integrals is connected with the inversion formula of Riemann and Mellin.[8]

22. *Applications to the Partial Differential Equations of Mathematical Physics.*

Integral equations frequently occur in the solution of problems of mathematical physics when a definite integral solution of a partial

[1] Pincherle and Amaldi, *Le operazioni distributive* (Bologna), 1901.
[2] *Acta Math.*, 1887; *Bologna Memoirs*, 1907.
[3] *Proc. Lond. Math. Soc.*, 1907; *Cambr. Phil. Trans.*, 1909.
[4] *Acta Societatis Fennicæ*, 1896, t. 21, No. 6. A paper by Cailler (*Darboux Bull.*, t. 23) may also be referred to.
[5] *Rend. Lincei*, ser. 4, vol. iv., pp. 694–700, pp. 792–799.
[6] *Acta Math.*, 1891, vol. xv., pp. 317–384.
[7] *Proc. London Math. Soc.*, ser. 2, vol. vi. (1907).
[8] *Acta Math.*, vol. xxv. (1902); *Math. Ann.*, Bd. 68 (1910).

differential equation is employed.[1] An integral equation is obtained as soon as the boundary conditions are introduced.

In some cases we have a single equation which has to serve for the determination of two unknown functions. Equations of this type were first considered by Cauchy in his memoir on the theory of waves, 1815. An interesting example is mentioned by Forsyth in his presidential address to the London Mathematical Society.[2] In many cases an equation of this type may be reduced to the ordinary form or to a system of equations by a special artifice. Systems of integral equations of various types are also considered by Murphy.[3]

A few examples of Fourier's method may be mentioned here. Lord Kelvin [4] used Laplace's solution,

$$V = \int_{-\infty}^{\infty} f(x + 2z\sqrt{t})e^{-z^2}dz$$

of the equation of the conduction of heat, $\frac{\partial^2 V}{\partial x^2} = \frac{\partial V}{\partial t}$, to solve the problem of the conduction of heat in an infinite solid with a plane face. He assumed $f(y) = 0$ for $y < 0$, $V = g(t)$ when $x = 0$. He was thus led to the equation

$$g(t) = \int_0^{\infty} f(2z\sqrt{t})e^{-z^2}dz$$

for the determination of f. This was solved with the aid of Fourier's theorem, but it may also be reduced to an equation of Laplace's type.

Schläfli [5] afterwards obtained the same equation, and expressed the solution in the form

$$f(x) = \frac{2}{\pi}\int_{-\infty}^{\infty} e^{-z^2} g\left(-\frac{x^2}{4z^2}\right)dz.$$

Lord Kelvin's solution is

$$f(x) = \frac{8}{\pi^2}\int_0^{\infty} dm \int_0^{\infty} \cosh x\sqrt{m} \cos x\sqrt{m} \cos 2mt\, g(t)dt.$$

The equation

$$\frac{\partial^2 V}{\partial z^2} + \frac{\partial^2 V}{\partial \rho^2} + \frac{1}{\rho}\frac{\partial V}{\partial \rho} - \frac{m^2}{\rho^2} V = 0$$

[1] This method may perhaps be justly ascribed to Fourier, as it is used by him in his 'Analytical Theory of Heat.' Poisson gave the solution of many partial differential equations in the form of definite integrals, but endeavoured to avoid the occurrence of integral equations. His efforts met with brilliant success as he obtained definite integral solutions which are exceedingly well adapted for the initial conditions occurring in the problems.

[2] *Proc. London Math. Soc.*, ser. 2, vol. iv., p. 431.

[3] *Cambr. Phil. Trans.*, vol. v. (1834).

[4] *Cambr. Math. Journ.* (1842–43), p. 170; *Math. and Phys. Papers*, i, p. 10.

[5] *Crelle's Journal*, Bd. 71–72 (1870).

is satisfied by a definite integral of the form

$$V = \int_a^\infty e^{-zt} J_m(\rho t)\phi(t)\, t\, dt.$$

We may determine $\phi(t)$ so that $V = f(\rho)$ when $z = 0$ by solving Hankel's integral equation; we may (when $m = 0$) determine $\phi(t)$ so that $V = F(z)$ when $\rho = 0$ by solving an integral equation of Laplace's type. The solution of one equation may be made to depend on that of the other when the solution of the partial differential equation for the given conditions is known. The differential equation

$$\frac{\partial^2 V}{\partial \rho^2} + \frac{1}{\rho}\frac{\partial V}{\partial \rho} + \frac{\partial^2 V}{\partial z^2} + k^2 V = 0$$

is satisfied by

$$V = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{\sin k\sqrt{r^2 - 2ar\mu + a^2}}{\sqrt{r^2 - 2ar\mu + a^2}}\,\phi(a)da \quad . \quad . \quad (1)$$

$$V = \int_p^q \frac{\sin k\sqrt{r^2 - 2ar\mu + a^2}}{\sqrt{r^2 - 2ar\mu + a^2}}\,\chi(a)da \quad . \quad . \quad (2)$$

and

$$V = \frac{1}{2\pi}\int_0^{2\pi} e^{ik\rho\sin a} f(z + i\rho\cos a)da \quad . \quad . \quad . \quad . \quad (3)$$

$$V = \int_0^\infty e^{-az} J_0(\rho\sqrt{a^2 + k^2})\psi(a)da \quad . \quad . \quad . \quad (4)$$

where $z = r\mu$, $\rho^2 + z^2 = r^2$.

If these expressions all represent the same solution we have when $\rho = 0$

$$f(z) = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{\sin k(z - a)}{z - a}\,\phi(a)da$$

$$f(z) = \int_p^q \frac{\sin k(z - a)}{z - a}\,\chi(a)da$$

$$f(z) = \int_0^\infty e^{-az}\,\psi(a)da$$

These integral equations are of the type considered by Hardy.[1] He has shown that if $f(z)$ is defined by an equation of the second type with m written in place of k, then the first equation is satisfied by $\phi(a) = f(a)$ if $k > m$. This result indicates that a solution of the partial differential equation that can be expressed in the form (2) can also be expressed in the form (1). By putting $z = 0$ in equations (1), (2), (3), (4), the

[1] *Proc. Lond. Math. Soc.* ser. 2, vol. vii. (1909), p. 445.

solutions of a large number of integral equations may be obtained indirectly with the aid of the partial differential equation. Other interesting integral equations are obtained by replacing k^2 by $-k^2$, or J_n by Y_n. Some of these may be solved by using the inversion formulæ for Fourier, Hankel, and Laplacian integrals.

Equations of Volterra's type may also be obtained from definite integral solutions of Laplace's equation; thus Le Roux [1] remarks that if $z(x,y,a)$ is a *principal solution* of the equation

$$\frac{\partial^2 z}{\partial x \partial y} = a\frac{\partial z}{\partial x} + b\frac{\partial z}{\partial y} + cz$$

then

$$\int_{x_0}^{x} f(a) z(x,y,a)\, da$$

will also satisfy the equation, and if this reduces to $g(x)$ when $y = y_0$, an equation of Volterra is obtained for the determination of $f(a)$. In the case of the equation of Euler and Poisson

$$\frac{\partial^2 z}{\partial x \partial y} - \frac{a}{x-y}\frac{\partial z}{\partial x} - \frac{b}{x-y}\frac{\partial z}{\partial y} + \frac{cz}{(x-y)^2} = 0$$

the particular solution of the type

$$z = (x-y)^n (x-a)^m$$

can be used to obtain Abel's integral equation. This is really only a modification of the method by which Poisson first obtained Abel's equation.

In many problems of vibrations a homogeneous integral equation of the first kind is obtained when the boundary conditions are introduced into a definite integral solution of a partial differential equation. Thus, in the case of the equation of a vibrating membrane [2]

$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + k^2 V = 0$$

which is satisfied by

$$V = \int_0^{2\pi} e^{ik[x\cos a + y \sin a]} \phi(a)\, da$$

the condition that $V = o$ on the boundary $x = x(\theta)$, $y = y(\theta)$, gives the homogeneous integral equation

$$o = \int_0^{2\pi} e^{ik[x(\theta)\cos a + y(\theta)\sin a]} \phi(a)\, da$$

According to a method described by the author the values of κ for which

[1] *Annales de l'École Normale Supérieure*, 1895, ser. 3ᵃ, t. 12.

[2] Other methods of treating the problem of a vibrating membrane with the aid of integral equations are given by Picard, *Rend. Palermo*, 1906; Boggio, *Rend. Lincei* 1907, p. 386; Bryon Heywood, *Thesis*, Paris, 1908; Sanielevici, *Annales de l'École Normale Superieure*, 1909, pp. 19–91.

an equation of this type can be satisfied may be obtained by considering the homogeneous integral equation of the second kind.[1]

$$\mu(\kappa)\phi(\theta) = \int_0^{2\pi} e^{i\kappa[x(\theta)\cos\alpha + y(\theta)\sin\alpha]}\phi(\alpha)d\alpha$$

and giving κ the different possible values for which the functions $\mu(\kappa)$ are zero. These functions may be determined by a method of successive approximations by expanding both sides in powers of κ.

The applications of Fredholm's equation to partial differential equations of elliptic type are very numerous. We must refer the reader to Andrae's dissertation[2] and papers by Picard[3] and Hilbert.[4] Equations of hyperbolic and parabolic type have also been discussed by Le Roux, Andrae, Holmgren, Goursat, Picard, Hadamard, Lauricella, Levi, Mason, Myller, and many other writers. A short account of the applications is given in Horn's 'Partial Differential Equations.'

23. *Applications to Problems in the Theory of Elasticity.*

The problems connected with the equilibrium of an elastic body when either the displacements or tractions are given over the surface has been reduced in various ways to the solution of a system of equations of Fredholm's type.

E. and F. Cosserat[5] effected this reduction in 1901, and solved the equations by a method of successive approximations.

Fredholm[6] applied his method of solving the integral equation of the second kind to show that the integrals of the differential equations which determine the equilibrium when the surface tractions are known, are meromorphic functions of the elastic constant. The theory has been discussed very thoroughly by Lauricella,[7] Marcolongo,[8] and Boggio;[9] the last author makes use of Green's functions.

The subject of the Prix Vaillant for the year 1907-08, proposed by the Paris Academy was that of the equilibrium of an elastic plate with fixed edges. The analytical problem is that of determining a solution of the equation

$$\nabla^4 u = \frac{\partial^4 u}{\partial x^4} + 2\frac{\partial^4 u}{\partial x^2 \partial y^2} + \frac{\partial^4 u}{\partial y^4} = f(x,y)$$

under the conditions that u and its normal derivative along the boundary are zero. The prize was divided between Hadamard,[10] Lauricella,[11] Korn,[12] and Boggio. The same problem has also been discussed by Marcolongo,[8] Zaremba,[13] and A. Haar.[14] The mathematical investiga-

[1] *Mess. Math.*, April 1910. [2] *Göttingen*, 1903. [3] *Rend. Palermo*, 1906.
[4] *Göttingen Nachrichten*, 1906. [5] *Comptes rendus*, t. 133 (1901).
[6] *Arkiv för mathematik och fysik*, Bd. 2, n. 28.
[7] *Il Nuovo Cimento*, 1907 (5), vol. xiii.
[8] *Rend. Lincei*, vol. xvi., ser. 5; *Toulouse Ann.*, 1908.
[9] *Rend. Lincei*, 1907, pp. 248, 441. [10] *Mémoires de l'Institut*, 1908.
[11] *Rend. Lincei*, 1907; *Acta Mathematica*, 1908–09.
[12] *Annales de l'Ecole Normale Supérieure*, ser. 3, vol. xxv. (1908).
[13] *Ibid.*, vol. xxv. (1909), p. 337.
[14] *Göttingen Nachrichten*, 1907.

tions connected with the problem are very long, and so we must refer to the original memoirs.

A singular integral equation of the second kind of the type

$$f(x) = \theta(x) + \frac{1}{2\pi}\int_{-\infty}^{\infty} \phi(t)dt \int_{-\infty}^{\infty} \theta(\xi) \cos t(\xi - x)d\xi$$

was obtained and solved by O. Tedone[1] in the problem of the elastic equilibrium of an indefinite circular cylinder.

The solution is given by the formula

$$\theta(x) = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{dt}{2 + \phi(t) + \phi(-t)} \int_{-\infty}^{\infty} f(\xi) \cos t(\xi - x)d\xi$$

24. *Bilinear and Quadratic Forms in an Infinite Number of Variables.*

The theory of quadratic forms in an infinite number of variables is propounded in a memoir by Hilbert,[2] and is applied to integral equations in a subsequent memoir. These memoirs contain many theorems of a fundamental nature which are of a very wide application. The theory is interesting, as it is full of striking analogies, the occurrence of point and band spectra being particularly noteworthy. Let

$$\kappa_{pq} = \kappa_{qp} \qquad \sum_{n=1}^{\infty} x_n^2 = (xx) \leq 1, \qquad (yy) \leq 1.$$

then the expression

$$\kappa(x,x) = \sum_{p=1}^{\infty}\sum_{q=1}^{\infty} \kappa_{pq} x_p x_q$$

is called a quadratic form in an infinite number of variables, and the expression

$$\kappa(x,y) = \sum_{p=1}^{\infty}\sum_{q=1}^{\infty} \kappa_{pq} x^p y^q$$

a bilinear form. When $\kappa_{pq} = \begin{matrix} 0 & p \neq q \\ 1 & p = q \end{matrix}$ the bilinear form is written (xy).

The bilinear form is said to be *limited* when it remains below a fixed limit for all values of x and y which satisfy the conditions $(xx) \leq 1$ $(yy) \leq 1$. If $\kappa(x,y)$ is limited, so also is $\kappa(x,x)$ and *vice versâ*. If $\sum_{pq} \kappa^2_{pq}$ converges, $\kappa(x,y)$ is called a limited continuous (*vollstetig*) form.

The expression $$\kappa_n(x,y) = \sum_{p=1}^{n}\sum_{q=1}^{n} \kappa_{pq} x_p y_q$$

is called the n^{th} section of $\kappa(x,y)$.

If $\kappa(x,y)$ is a limited form, $\kappa_n(x,y)$ converges for fixed values of x,y to $\kappa(x,y)$ as $n \to \infty$, provided $(xx) \leq 1$ $(yy) \leq 1$. The convergence to the limit is uniform provided the series Σx_i^2, Σy_i^2 converge uniformly.

[1] *Rend. Lincei*, 1904, p. 232. [2] *Göttingen Nachrichten*, 1906.

The fold (*Faltung*) of two linear forms

$$L(x) = \sum_{=1}^{\infty} l_i x_i \qquad M(x) = \sum_{=1}^{\infty} m_i x_i$$

is defined by the equation

$$L(\cdot)M(\cdot) = \sum_i l_i m_i$$

A linear form $\Sigma l_i x_i$ is said to be *limited* when Σl_i^2 converges. For linear forms we have the inequality

$$(\sum_i l_i x_i)^2 < (\sum_i l_i^2)(\sum_i x_i^2).$$

When $\kappa(x,x)$ is a limited continuous quadratic form the solution of the equation

$$\bar{L}_p(y) = \lambda_p \bar{L}_p(\cdot)\kappa(\cdot,y) \quad . \quad . \quad . \quad . \quad (1)$$

is possible by a limited linear form $L_p(y)$ for certain quite definite real values of λ_p. These values of λ_p, which in the present case can only condense at infinity,[1] are called the *characteristic values* (*Eigenwerte*), and $\bar{L}_p(y)$ the *characteristic forms*. The latter can be chosen so that

$$\bar{L}_p(\cdot)\bar{L}_q(\cdot) = 0 \qquad \text{if } q \neq p.$$
$$\bar{L}_p(\cdot)\bar{L}_p(\cdot) = 1$$

A set of linear forms which satisfy these equations are said to form an *orthogonal system*.

We have the relations [2]

$$\kappa(x,x) = \sum_p \frac{[\bar{L}_p(x)]^2}{\lambda_p} \quad . \quad . \quad . \quad . \quad (2)$$

$$(xx) = \sum_1^{\infty} [\bar{L}_p(x)]^2 \quad . \quad . \quad . \quad . \quad (3)$$

The aggregate of the characteristic values λ_p is called the *spectrum* of the quadratic form. For each value of γ outside the spectrum there exists a uniquely defined resolvent

$$K(\lambda\,;\ x,x) = \sum_{p=1}^{\infty} \frac{[\bar{L}_p(x)]^2}{1 - \dfrac{\lambda}{\lambda_p}} \quad . \quad . \quad . \quad . \quad (4)$$

which satisfies the equation

$$K(\lambda\,;\ x,y) - \lambda\kappa(x,\ \cdot\ )\,K(\lambda\,;\ \cdot\ ,y) = (xy)$$

If $\kappa(x,y)$ is a *limited* but no longer a *continuous* form, the equation (1) is generally satisfied by an aggregate of real values of λ_p, which are arranged in continuous bands, and there may be isolated points in the

[1] The value $\lambda_p = \infty$ may enter either simply or multiply among the characteristic values.

[2] The resolution of a quadratic form into a sum of squares has been further developed by Toeplitz and von Koch (*Math. Ann.*, 1910, Bd. 69, p. 266). The latter gives a method depending on the use of infinite determinants by which the reduction may be actually effected.

intervals between the bands. A certain limited form $\sigma(\lambda\,;\,x,x)$, called the *spectral form* is associated with each point of a band, and the equations (3), (4), and (2) are now replaced by

$$\kappa(x,x) = \sum_{p=1}^{\infty} \frac{[\overline{L}_p(x)]^2}{\lambda_p} + \int_s \frac{d\sigma(\mu\,;\,x,x)}{\mu},$$

$$K(\lambda\,;\,x,x) = \sum_{p=1}^{\infty} \frac{[\overline{L}_p(x)]^2}{1-\dfrac{\lambda}{\lambda_p}} + \int_s \frac{d\sigma(\mu\,;\,x,x)}{1-\dfrac{\lambda}{\mu}}$$

$$(xx) = \sum_{p=1}^{\infty} [\overline{L}_p(x)]^2 + \int_\sigma d\sigma(\mu\,;\,xx).$$

The quantities λ_p can also possess points of condensation in the finite part of the axis of real quantities.

The proofs of these general theorems are very difficult, some of the results have, however, been established in a simpler way by Hilbert's followers.[1] The literature on the subject is now quite extensive.

25. *Linear Equations in an Infinite Number of Variables.*

The theory of linear equations with an infinite number of unknowns which was first considered by G. W. Hill,[2] Poincaré,[3] and Helge von Koch[4] in connection with the theory of infinite determinants has been the subject of some recent investigations by Hilbert, and the results have been simplified and extended by Toeplitz. The equations considered are of the form

$$\sum_{m=1}^{\infty} a_{nm} z_m = C_n \quad \ldots \quad (1) \qquad (n=1, 2 \ldots \text{to } \infty)$$

and attention is paid only to the solutions for which the series

$$\sum_{m=1}^{\infty} |z_m|^2$$

is convergent.

Hilbert and Toeplitz discuss the case when the quantities a_{nm} are the coefficients of a *limited* bilinear form and the series

$$\sum_{m=1}^{\infty} |a_{nm}|^2$$

converges for all values of n. Then the convergence of the series

$$\sum_{n=1}^{\infty} |C_n|^2$$

is assumed as a *necessary* condition for the solubility of the equations,

[1] Reference may be made to the Göttingen dissertations by Hellinger (1907) and Weyl (1908); and papers by Hellinger and Toeplitz (*Göttingen Nachrichten*, 1906), Hellinger (*Crelle*, Bd. 136, 1909), Toeplitz (*Rend. Palermo*), Plancherel (*Math. Ann.*, Bd. 67, p. 511), Riesz (*Gött. Nachr.*, 1910), Hilbert (*Gött. Nachr.*, 1910).

[2] *Acta Math.*, 1886, t. 8, pp. 1–36. The memoir was first published in 1877.

[3] *Bull. de la Soc. Math. de France*, 1886, t. 14, pp. 77–90.

[4] *Acta Math.*, 1891, t. 15, pp. 53–63; *ibid.*, 1892–93, t. xvi., pp. 217–295.

and an attempt is made to find a criterion for determining whether this condition is sufficient or not.

The theory has been considerably extended by E. Schmidt. He shows that the necessary and sufficient conditions for the solubility of the equation consists in the convergence of a certain quadratic form.

$$\sum_{n=1}^{\infty}\left|\sum_{v=1}^{n}\overline{\gamma_{nv}}\,C_v\right|^2$$

He constructs a set of orthogonal forms in the following way:

Let
$$A_n(x) = \bar{a}_{nx} \qquad \begin{matrix} n=1,2\ldots\infty \\ x=1,2\ldots\infty \end{matrix}$$
$$z(x) = z_x$$

where $\bar{a}_{nx}$ denotes the conjugate complex quantity to a_{nx}.

Put
$$C_1(x) = A_1(x)$$
$$C_2(x) = A_2(x) - C_1(x)\,\frac{A_2(\cdot)\bar{C}_1(\cdot)}{C_1(\cdot)\bar{C}_1(\cdot)}$$
$$C_n(x) = A_n(x) - \sum_{\rho=1}^{n} C_\rho(x)\,\frac{A_n(\cdot)\bar{C}_\rho(\cdot)}{C_\rho(\cdot)\bar{C}_\rho(\cdot)}$$

then these forms $C_\rho(x)$ are orthogonal, and if

$$D_n(x) = C_1(x) + C_2(x) + \ldots + C_n(x)$$

the quantities $\gamma_{v\mu}$ are defined by the equation

$$A_v(x) = \sum_{\mu=1}^{n}\gamma_{v\mu}D_\mu(x).$$

If $M(x)$ is an arbitrary linear form, the form

$$P(x) = M(x) - \sum_{v=1}^{\infty} C_v(x)M(\cdot)\bar{C}_v(\cdot)$$

is called the form (or function) *perpendicular* to the forms $A_v(x)$ or $C_v(x)$. Since the conditions of orthogonality are

$$C_v(\cdot)\bar{C}_\mu(\cdot) \begin{matrix} =0 & v \neq \mu \\ =1 & v=\mu \end{matrix}$$

we have
$$P(\cdot)\bar{C}_\mu(\cdot) = 0$$

and this shows that $P(x)$ is orthogonal to all the C_μ's. Schmidt gives several different methods of solving the set of linear equations, but for these we must refer to the original memoir.

The importance of systems of linear equations with ∞' unknowns depends upon the fact that an integral equation of the form

$$f(x) = \phi(x) - \lambda\int_a^b \kappa(x,t)\phi(t)dt$$

or of the form

$$f(x) = \int_a^b \kappa(x,t)\phi(t)dt$$

may be reduced[1] to such a set of equations by using a system of orthogonal functions $\psi_m(x)$ belonging to the interval (a,b). Putting

$$f_m = \int_a^b f(x)\psi_m(x)dx$$

$$\phi_n = \int_a^b \phi(x)\psi_m(x)dx$$

$$\kappa_{mn} = \int_a^b\int_a^b \kappa(x,t)\psi_m(x)\psi_n(t)dxdt$$

we find that the above equation may be replaced by

$$f_m = \phi_m - \lambda \sum_{n=1}^{\infty} \kappa_{mn}\phi_n$$

$$f_m = \sum_{n=1}^{\infty} \kappa_{mn}\phi_n$$

respectively, and so all the above results may be applied to them directly; the transition from the quantities ϕ_m to the function $\phi(x)$ being finally effected by means of the expansion theorem, or one of the alternative methods suggested by Riesz and Fischer.

The theory of linear equation has been further developed by E. H. Moore,[2] who comprises it in a form of general analysis.

A report on the development and present state of the theory has been published recently by Helge v. Koch. *Compte rendu du Congrès des Mathématiciens tenu à Stockholm* (1909).

The solution of systems of linear equations in ∞,[2] unknown quantities by means of infinite determinants, is of very great importance in the theory of linear differential equations of the type[3]

$$\frac{d^2w}{dt^2} + 2k\frac{dw}{dt} + (\Theta_0 + 2\Theta_1 \cos 2t + 2\Theta_2 \cos 4t + -)\, w = \mathrm{F}(t)$$

which occur in the lunar theory, and in many acoustical and mechanical problems. The problems of the lunar theory have been dealt with in this way by Hill, Poincaré, and others.

The various mechanical acoustical and optical problems considered by Lord Rayleigh[4] and A. Stephenson[5] possess the interesting feature that a certain state of equilibrium of a mechanical system is rendered unstable by the action of a periodic force which does not tend directly

[1] Hilbert, *Göttingen Nachrichten*, 1906, Heft 4. A similar method has been developed by A. C. Dixon (*Proc. Lond. Math. Soc.*, ser. 2, vol. vii., 1909).

[2] *Rome Congress*, 1908, vol. ii., pp. 98–111; 'Lectures at the New Haven Mathematical Colloquium,' Yale Univ. Press, 1910.

[3] A good account of the theory is given in Forsyth's *Theory of Differential Equations*, vol. iv., ch. 8.

[4] On the maintenance of vibrations by forces of double frequency and on the propagation of waves through a medium endowed with a periodic structure (*Phil. Mag.*, 1887, vol. xxiv., pp. 145–59; *Scientific Papers*, vol. iii.).

[5] *Quarterly Journal*, 1906; *Phil. Mag.*, 1907, vol. xiv., p. 115; *ibid.*, 1908; *Manchester Memoirs*, 1908, vol. lii.

to displace the system from this position of equilibrium: owing to the instability a small chance deviation from the state of equilibrium grows into a large disturbance. Probably the best-known example of this kind of action is that form of Melde's experiment in which a fine string is maintained in transverse vibration by connecting one of its extremities with the vibrating prong of a massive tuning-fork, the direction of motion of the point of attachment being *parallel* to the length of the string. The effect of the motion is to render the tension of the string periodically variable, and the string may settle down into a state of permanent and vigorous vibration whose period is *double* that of the point of attachment.[1]

Stephenson has developed the theory so as to obtain a mechanical analogy of phosphorescence. This and other optical analogies indicated by Rayleigh suggest strongly that the mathematical theory of the emission of light depends either upon systems of equations with an infinite number of unknown quantities or on integral equations of an analogous type. Hilbert's theory of quadratic forms in an infinite number of variables points to the same conclusion.

The chief difficulty from the physical point of view is the correct formulation of the equations. When this has been effected the mathematical theories may be of very great service.

26. *Singular Integral Equations.*

When the limits of integration are infinite, or the kernel possesses singularities of a certain kind, the results of the ordinary theory of linear integral equations no longer hold, and in particular the homogeneous integral equation of the second kind may possess an infinite number of linearly independent solutions corresponding to a given characteristic number λ. For instance, in the case of Fourier's integral

$$f(x) = \int_0^\infty \cos xt\phi(t)dt$$

if the inversion formula holds for the function $f(x)$ we have also

$$\phi(x) = \frac{2}{\pi}\int_0^\infty \cos xtf(t)dt.$$

Consequently the function

$$\psi(x) = f(x) + \sqrt{\frac{\pi}{2}}\phi(x)$$

satisfies the homogeneous integral equation

$$\psi(x) = \sqrt{\frac{2}{\pi}}\int_0^\infty \cos xt\psi(t)dt,$$

and so it follows that for the characteristic number $\sqrt{\frac{2}{\pi}}$ this homo-

[1] Cf. Tyndall's *Sound*, 3rd ed., ch. iii.

geneous integral equation possesses an infinite number of linearly independent solutions.

An example of another nature is provided by the integral

$$\int_o^\pi \frac{\sin(1-a)(\xi-u)}{\sin(\xi-u)} \frac{du}{(\sin u)^a} = \frac{\pi}{(\sin\xi)^a} \quad (o < a < 1)$$

obtained by Hardy.[1] In this case the kernel is infinite, for $(\xi = o, u = \pi)$, $(\xi = \pi, u = o)$ and the normal function $(\operatorname{cosec}\xi)^a$ is infinite for $(\xi = o, \pi)$.

Integral equations with the kernel $(s+t)^{-1}$ are of special interest, and have been studied by Stieltjes,[2] Hilbert, and Weyl. This kernel is, of course, derived from e^{-sx} by forming the *iterated function*

$$\int_o^\infty e^{-sx} \cdot e^{-tx} dx.$$

Stieltjes shows that the equation

$$f(x) = \int_o^\infty \frac{\phi(t)}{x+t} dt$$

may be solved by means of the formula

$$\phi(t) = \frac{1}{i\pi} \operatorname*{Lt}_{\epsilon \to o} [f(-s-i\epsilon) - f(-s+i\epsilon)]$$

Hilbert[3] shows that by using the orthogonal system $\sin p\pi t$ we may pass from the kernel $\frac{1}{s+t}$ to a quadratic form of the type

$$\sum_{p=1}^\infty \sum_{q=1}^\infty \frac{x_p x_q}{p+q} + K^*(x)$$

where $K^*(x)$ is a *limited continuous* form. Hilbert[4] shows that the form $\sum_{pq} \frac{x_p x_q}{p+q}$ is limited, and another proof of this result has been given by F. Wiener.[5]

Weyl has considered the kernel $\frac{1}{s+t}$ in connection with the orthogonal functions of Laguerre. The kernel is also of importance in the theory of differential equations of the hypergeometric type.[6]

The integral equation associated with a linear differential equation becomes singular when the interval which defines the limits of the integral contains a singularity of the differential equation. The simplest case arises when the differential equation is

[1] *Quarterly Journal*, 1901, vol. xxxii., p. 384. The paper contains another example of a similar nature.

[2] *Annales de Toulouse*, 1894, t. 8; 1895, t. 9. See also Borel's *Leçons sur les séries divergentes*.

[3] *Lectures*, 1906, Summer Semester.

[4] *Mathematische Gesellschaft*, 1907; cf. Weyl's dissertation, p. 83.

[5] *Math. Ann.*, 1910, Bd. 68, p. 361.

[6] Cf. H. A. Webb, *Phil. Trans. A.*, vol. cciv., pp. 481–497.

$$\frac{d^2y}{dx^2} + \lambda y = 0$$

and the interval extends to infinity. The characteristic values of λ are then everywhere dense along the positive half of the λ axis, and so form a continuous spectrum or a band spectrum. Fourier's integral formula now takes the place of the expansion theorem. The representation of arbitrary functions by means of the normal functions of a differential equation with a singular point at the end of the interval is very complex. In addition to a continuous spectrum a point spectrum can also occur: we thus have a mixed representation, partly by a series formed according to Fourier's rule and partly by an integral analogous to Fourier's double integral. It can also happen that an integral representation is obtained in which the integral is taken over several separate intervals or bands, and the isolated points of the spectrum are in the different intervals between the bands.

Wirtinger [1] first came across such a distribution of singular values in the case of a vibrating string of infinite length; he called the distribution a *band spectrum*. The discovery of the existence of a band spectrum in the year 1897 is quite noteworthy.

The general theory of band spectra has been given by Hilbert [2] in his theory of quadratic forms in an infinite number of variables. This theory seems to cover all the cases that have so far been treated, and it must be considered a very noteworthy achievement on Hilbert's part to have established theorems of such very wide application.

The differential equations to which the theory has been applied are of the form

$$L(u) + \lambda u \equiv \frac{d}{ds}\left[s^2 l(s)\frac{du}{ds}\right] - q(s)u + \lambda u = 0$$

where $l(s)$, $q(s)$ behave regularly as analytic functions in the neighbourhood of the strip $o \leq s \leq 1$ of the real axis, and $l(s)$ is everywhere positive for $o \leq s \leq 1$; also $l(o) = 1$. At the end point $s = 1$ an arbitrary homogeneous boundary condition is ascribed.

The theory is due chiefly to Hilb [3] and Weyl,[4] who obtain a representation of the form

$$f(s) = \sum_{i=1}^{n} \psi_i(s)\int_o^\infty f(t)\psi_i(t)dt$$
$$+ \int_{\frac{1}{4}+q(o)}^\infty \psi(s,\lambda)\int_o^\infty f(t)\psi(t,\lambda)dt\,d\lambda$$

the integrals being absolutely and uniformly convergent if

$$\int_o^1 [f(s)]^2 ds, \qquad \int_o^1 [L(f)]^2 ds \qquad \int_o^1 \left|\frac{f(s)}{\sqrt{s}}\right| ds$$

converge. The functions $\psi_i(s)$ $\psi(s,\lambda)$ are solutions of the differential equation for appropriate values of λ. Hilb's results have also been

[1] *Math. Ann.*, 1897, Bd. 48, p. 387.
[2] *Göttingen Nachrichten*, 1906, pp. 157–227, pp. 439–80.
[3] *Math. Ann.*, 1908, Bd. 66, p. 1. [4] *Ibid.*, 1910, Bd. 68, p. 220.

extended by Plancherel.[1] Hilb also considers the more general equation

$$L(u) = \frac{d}{ds}\left(s\frac{du}{ds}\right) + \frac{\lambda h(s) - g(s)}{s} u = o$$

where $g(s)$, $h(s)$ are analytic functions of s which have the character of integral functions is an interval $(o, 1)$ which includes both limits. Finally $g(s)$, $h(s)$ are real for real values of s, and $g(s) > 1 \quad h(s) > a > o$ $o \quad s < 1, \quad h(o) = 1$.

The integral representation is discussed with the aid of a Green's function belonging to the differential equation.

The general theory of differential equations when the independent variable has an infinite range of values is discussed by Weyl. He shows that all the integrals of the equation

$$\frac{d}{ds}\left[p(s)\frac{du}{ds}\right] - q(s)u = o$$

tend to finite limits as $s \to \infty$ if the integral

$$\iint\limits_{o \leq t \leq s \leq \infty} \frac{q(t)}{p(s)}\, dt\, ds$$

is convergent. This condition is necessary and sufficient except when $q(s) \equiv o$.

Singular integral equations connected with differential equations of higher orders have been considered by the author.[2] There is an inversion formula of the type

$$f(x) = \int_o^\infty J_\nu(xt) Y_\nu(xt) t\phi(t) dt \qquad (\nu > -\tfrac{1}{2})$$

$$\phi(t) = -2\pi \int_o^\infty \frac{d}{dt}\left\{ J_\nu^2(xt) \right\} xf(x) dx$$

for instance, associated with the differential equation of the third order satisfied by $xJ_\nu^2(xt)$—viz.,

$$\frac{d^3z}{dx^3} + \left(4t^2 + \frac{1 - 4\nu^2}{x^2}\right)\frac{dz}{dx} - (1 - 4\nu^2)\frac{z}{x^3} = o.$$

Singular integral equations connected with the formula[3]

$$f(x) = \int_{-\infty}^{\infty} \frac{\sin m(x-t)}{x-t} f(t) dt$$

have been discussed by Hardy following a remark made by the author. The formula

[1] *Math. Ann.*, 1909, Bd. 67, Heft 4.

[2] *Proc. Lond. Math. Soc.*, 1906–07, ser. 2, vol. iv., p. 483.

[3] This formula has been investigated by Hardy (*Proc. Lond. Math. Soc.*, ser. 2, vol. vii., p. 445). Some remarkable definite integrals are obtained in the course of the work.

$$F(\lambda) = \int_{-\infty}^{\infty} \frac{J_{\mu}\{m(t-\lambda)\}}{(t-\lambda)^{\mu}} f(t)dt$$

$$\frac{4\cos\mu\pi}{m(1-2\mu)} f(x) = \int_{-\infty}^{\infty} \frac{J_{1-\mu}\{m(\lambda-x)\}}{(\lambda-x)^{1-\mu}} F(\lambda)d\lambda$$

is quite noteworthy. Sufficient conditions for its validity are given by Hardy.

27. *Miscellaneous Physical Applications.*

In a short abstract of a memoir which does not appear to have been printed Rouché[1] indicates a number of problems in electro-magnetism, mechanics, and viscosity which can be solved by means of integral equations; but none of these problems appear to have been dealt with by subsequent writers.

In 1906 Fredholm gave a theory of the lines in the spectrum which promises to have interesting physical applications.

Starting out with the idea of finding systems analogous to those considered by Rayleigh and Ritz where the fundamental vibrations obey laws of the same general type as the vibrations which give rise to the spectra of hydrogen and other elements, Fredholm considers a finite region of space over which matter is spread continuously, and denotes by $w(t,x,y,z)$ the displacement of a particle from its position of equilibrium at time t, supposing for simplicity that each particle only possesses one degree of freedom. He supposes that the force F exerted by one particle on another is given by an expression of the form

$$F = \Phi(\xi,\eta,\zeta\,;\ x,y,z)\ [w(\xi,\eta,\zeta) - w(x,y,z)] \quad . \quad . \quad (1)$$

where Φ is a symmetric function of (ξ,μ,ζ); (x,y,z), so that action and reaction may be equal and opposite. He is thus led to an equation of motion of the form

$$\rho\frac{\partial^2 w}{\partial t^2} = \iiint \Phi(\xi,\eta,\zeta\,;\ x,y,z)\ [w(\xi,\eta,\zeta) - [w(x,y,z)]\ d\xi d\eta d\zeta$$

and the existence of a fundamental vibration of the type

$$w = e^{i\lambda t}u(x,y,z)$$

depends upon the possibility of satisfying the homogeneous integral equation

$$u(x,y,z)\left[\iiint \Phi(\xi,\eta,\zeta\,;\ x,y,z)d\xi d\eta d\zeta - \lambda^2\right]$$
$$= \iiint \Phi(\xi,\eta,\zeta\,;\ x,y,z)u(\xi,\eta,\zeta)d\xi d\eta d\zeta \quad . \quad . \quad . \quad (2)$$

In order to simplify the analysis Fredholm assumes that

$$\iiint \Phi(\xi,\eta,\zeta\,;\ x,y,z)d\xi d\eta d\zeta = \sigma \quad . \quad . \quad . \quad . \quad (3)$$

where σ is constant. The integral equation then becomes

[1] *Comptes rendus*, 1860, Paris, t. 51.

$$(\sigma - \lambda^2\rho)u(x,y,z) = \iiint\Phi(\xi,\eta,\zeta\,;\ x,y,z)u(\xi,\eta,\zeta)d\xi d\eta d\zeta$$

and since Φ is a symmetric function it can be satisfied for the real values of λ which are given by the transcendental equation

$$D\left(\frac{1}{\sigma - \lambda^2\rho}\right) = 0.$$

The values of λ have a point of condensation at $\sqrt{\sigma/\rho}$. The special assumption (3) is probably not necessary, as the values of λ for which (2) can be satisfied will also obey a law of the type required. The properties of the more general equation (2), however, have not been thoroughly investigated.

Fredholm's theory of the spectrum has been developed by Schaefer,[1] who obtains a dispersion formula by introducing a forced vibration with an x-component of the type

$$X(\xi,\eta,\zeta,t) = U(\xi,\eta,\zeta)\cos nt.$$

This leads to a non-homogeneous integral equation of the type

$$p.U(x,y,z) = u(x,y,z) - \mu\iiint\Phi(\xi,\eta,\zeta\,;\ x,y,z)\ u(\xi,\eta,\zeta)dd\xi\eta d\zeta$$

where

$$\mu = \frac{1}{\sigma - n^2\rho}$$

and Schmidt's expansion theorem gives

$$u(x,y,z) = p\ .\ U(x,y,z) + \mu p\sum_1^\infty{}_\kappa \frac{\psi_\kappa(x,y,z)}{\mu_\kappa - \mu}\iiint U(\xi,\eta,\zeta)\psi_\kappa(\xi,\eta,\zeta)d\xi d\eta d\zeta$$

where

$$\mu_\kappa = \frac{1}{\sigma - n_\kappa^2\rho} = \frac{T_\kappa^2}{\sigma T_\kappa^2 - 4\pi^2\rho}$$

T_κ being a fundamental period of vibration and ρ the density. By introducing an assumption of the form

$$D_x = \cos nt[U(x,y,z) + a\iiint u(\xi,\eta,\zeta)d\xi d\eta d\zeta]$$

for the x-component of the dielectric displacement, and supposing that $U(x,y,z)$ does not vary appreciably over the region of integration, Schaefer is finally led by means of Maxwell's equations to a dispersion formula of the type

$$\nu^2 = b + \sum_1^\infty{}_\kappa \frac{M_\kappa}{1 - \frac{T_\kappa^2}{T^2}}$$

where ν is the refractive index, T_κ a natural period of vibration, and T the period of the external force.

Another application of an integral equation to the theory of the

[1] *Ann. d. Physik*, 1909, Bd. 28, p. 421; 1909, Bd. 29, p. 715. Schaefer simplifies the work by considering an analogous problem in one dimension. His analysis is applied here to the three-dimensional problem.

spectrum where use is made of a model atom in which electricity is distributed over concentric spherical shells has been made by Jeans.[1]

The applications of integral equations to the theory of the spectrum are at present in their infancy; but there seems to be a very promising field of research in this direction. It is possible for an integral equation (or a set of linear equations with ∞' unknown quantities) to give an account of band spectra and continuous spectra. If matter is discontinuous it is probable that Hilbert's theory of quadratic forms and linear equations in an infinite number of variables should be of primary importance. In this connection it may be mentioned that the general expansion theorems for singular integral equations obtained by Hilb and Weyl seem to suggest a general dispersion formula of the type

$$\nu^2 = b + \sum_1^\infty \frac{M_\kappa}{1 - \frac{T_\kappa^2}{T^2}} + \int_0^\infty \frac{F(\lambda)d\lambda}{1 - \frac{\lambda}{T^2}}$$

which would be applicable when band spectra or continuous spectra exist. In such a formula the function $F(\lambda)$ may be zero for a number of intervals.

The fact that a large number of types of integral equations or linear equations in an infinite number of unknown quantities may be replaced by a homogeneous integral equation of the form

$$\int_a^b [g(s,t) - \lambda\kappa(s,t)]\,\phi(t)dt = 0$$

may be of some interest in connection with the existence of different series of lines in the spectrum of an element, for it is known[2] that in many cases the values of λ for which an equation of this type can be satisfied are the roots of a set of functions $\mu_1(\lambda)$, $\mu_2(\lambda)$, $\mu_3(\lambda)$, and it is possible that each of these functions may be associated with a series of lines in the spectrum.

The study of integral equations of this type promises results of some interest. It may be worth while to investigate the changes which occur in the values of the roots when a parameter θ, on which the functions $g(s,t)$ $\kappa(s,t)$ depend, suffers a small change $\delta\theta$. The results would probably have some application to the theory of the effect of an increase of pressure or temperature on the lines in the spectrum.

With regard to the other physical applications of Fredholm's equation, it may be mentioned that Poincaré[3] has treated some problems in the diffraction of Hertzian waves, and W. H. Jackson[4] has shown that a problem in the theory of radiation considered by Schuster may be reduced to the solution of Fredholm's equation. Applications of Fredholm's equation to the theory of the tides have been made by

[1] 'The Mechanism of Radiation' (*Phil. Mag.*, ser. 6, vol. ii., p. 421).

[2] *Mess. Math.*, April 1910.

[3] *Comptes rendus*, 1909, t. 148, p. 449; *Lectures at Göttingen*, 1909; Teubner, Leipzig, 1910.

[4] *Bull. Amer. Math. Soc.*, 1910.

Bryon Heywood[1] and Poincaré,[2] while the applications to problems in the conduction of heat are very numerous.

Lord Rayleigh[3] has obtained an integral equation of the first kind when studying a dynamical problem in illustration of the kinetic theory of gases. He considers a number of equal masses which are not free to wander indefinitely, but are moored to fixed points by similar elastic attachments so that they perform vibrations of a certain type. Let r be some quantity by which the amplitude of the vibration is measured, and suppose that the number of masses whose component velocity in the direction of the axis of x lies between u and du is represented by

$$\phi(r,u)du$$

where ϕ is a known function, which depends upon the law of vibration. Then if $\chi(r)dr$ denotes the number of vibrations for which r lies between $r+dr$, the law of distribution of u is given by

$$f(u) = \int \chi(r)\, \phi(r,u) dr.$$

If this law of distribution remains permanent when there are collisions between the different masses, we must have

$$f(u) = \frac{N\sqrt{h}}{\sqrt{\pi}} e^{-hu^2}$$

and the problem is to determine the law of distribution of the amplitude—*i.e.*, to determine $\chi(r)$—so that $f(u)$ may have this value.

Lord Rayleigh considers in particular the case when $u = r \cos \theta$ and all angles θ are equally likely. The integral equation is then

$$f(u) = \frac{1}{2\pi}\int_u^\infty \frac{\chi(r)dr}{\sqrt{r^2 - u^2}}$$

and is of Abel's type. The solution for

$$f(u) = N\sqrt{\frac{h}{\pi}}e^{-hu^2}$$

is given by

$$\chi(r) = 4Nhr\, e^{-hr^2}$$

28. *Non-linear Integral Equations.*

The method of successive approximations has been applied to the study of non-linear integral equations by Block,[4] Orlando,[5] d'Adhémar[6] Schmidt,[7] and others. The method indicates that the solution of an equation of the type

[1] *Thesis*, 1908, Paris; Liouville's *Journal*, 1908
[2] *Lectures at Göttingen*, 1909; Teubner, Leipzig, 1910.
[3] *Phil. Mag.*, 1891, vol. xxxii., pp. 424–45.
[4] *Arkiv för Math. u. Phys.*, 1907, Stockholm, Bd. 3, Häfte 3–4.
[5] *Rend. Lincei*, 1907, vol. xvi., 2nd ser.
[6] *Bull. de la Société Math. de France*, 1908, t. xxxvi.
[7] *Math. Ann.*, 1908, Bd. 65.

$$f(x) + \lambda\int_0^1 \kappa(x,y)\mathrm{F}\{f(y)\}\,dy = \mathrm{G}(x) \quad . \quad . \quad . \quad (1)$$

is unique for values of λ whose moduli are sufficiently small, but the equation appears to possess a 'band spectrum' for values of λ whose moduli are greater than a certain number.

Equations of the type

$$f(x) = \phi(x) + \lambda\int_a^b \kappa(x,y)\phi(y)dy + \mu\int_a^b\int_a^b g(x,y,z)\phi(y)\phi(z)dydz + \quad . \qquad (2)$$

are of considerable interest, partly on account of their connection with Volterra's expansion theorem for functions which depend on other functions and partly for their connection with non-linear differential equations. There appears to be an intimate connection between equations of the forms (1) and (2) because a non-linear differential equation may be reduced to either form by employing different artifices. For instance the equation

$$\frac{d^2y}{dx^2} + \lambda y^2 + g(x) = 0$$

is reduced to the form

$$y(x) = \int_0^1 \mathrm{G}(x,t)[\lambda\{y(t)\}^2 + g(t)]dt$$

by using a Green's function of the differential equation $\frac{d^2y}{dx^2} = 0$. It is also reduced to the form

$$\phi(x) = \lambda\int_0^1\int_0^1 \mathrm{G}(x,s)\mathrm{G}(x,t)\phi(s)\phi(t)dsdt + g(x)$$

by the assumption

$$y(x) = \int_0^1 \mathrm{G}(x,t)\phi(t)dt.$$

Examples of this type may of course be multiplied indefinitely. For the purpose of studying equations of type (1) it is convenient to consider some well-known equation such as the pendulum equation

$$\frac{d^2y}{dx^2} + k^2 \sin y = 0$$

reducing it to an integral equation of type (1) by the first method.

For a discussion of the properties of equations of type (2) we must refer to Schmidt's memoir.

A Report on Solubility. Part I. *By* J. Vargas Eyre, *Ph.D.*

[Ordered by the General Committee to be printed *in extenso.*]

I. Introduction.

This report is the outcome of a systematic study of the literature bearing on the question of the solubility of substances in general; the material is classified chronologically and according to subject; and contains a brief statement of the main conclusions arrived at by the various authors.

From almost the earliest times to the present the solubility of substances has formed the subject of scientific inquiry; a vast amount of work has been recorded and many conflicting opinions have been from time to time advanced. The published data were collected by Storer (1864) to form the first Dictionary of Solubility; the later admirable compilations of Comey (1894) and Seidel (1906) have brought this part of the subject well up to date.

The importance of the study of solubility is to be emphasised; indeed, there can be little doubt that the time is not far distant when determinations of solubility will be more generally recognised as indicative of the reactivity or condition of saturation of substances. In view of this conclusion it was deemed desirable to classify all the published work of general and theoretical interest, not only to show the present position but to indicate more clearly the direction future work on this subject should take.

Classification of work that has been carried out with so many different substances and under very divers conditions presented considerable difficulty, more especially as the space to be occupied by this report was small. The scheme of classification adopted is the result of an attempt to avoid repetition and cross references as far as possible, and to make the report quite brief.

In compiling this report the original papers have for the most part been consulted, but with so extensive a literature it was not always possible to do this. All references are made to the original papers.

For convenience of publication it was deemed desirable that this report be divided into two parts, the first part to record work published up to and including 1895, the second part up to and including 1910.

II. Methods of Determination.

The rapid advance made in the construction of scientific apparatus within recent years has necessarily detracted much from the value of the early work on solubility by enabling a far greater degree of accuracy to be obtained at the present time.

It is, however, to be lamented that notwithstanding most skilful manipulation and the use of improved apparatus, some of the more recent published work loses in value from the fact that no detailed description is given of the method employed to obtain the results published.

The purpose of this section is not so much to give a complete record of the various methods employed for determining the solubility of any particular substance, but rather to indicate those of greater interest, and more especially to emphasise the importance of describing the method used so that the value of the results of work on this subject may be properly judged.

A.—*Solubility of Solids.*

The records of work to elucidate the phenomenon of solubility carried out prior to the middle of the nineteenth century are possessed only of historical interest.

1843. *Poggiale*[12] made particular mention of the difficulty in obtaining perfectly saturated solutions.

He made use of the following two methods given by Gay-Lussac:—

(1) Gradually heating water with excess of salt.

(2) Cooling a hot saturated solution.

He stated that both these methods are valid provided always precautions are taken to shake the mixture repeatedly at constant temperature for about three hours. The solubilities were estimated by evaporating and weighing the residue.

1865. In reviewing his previous work* *Kremers*[21] found that his earlier values, obtained by allowing a hot saturated solution to cool to the room temperature and immediately taking a sample, did not agree well with those obtained either by Gay-Lussac or by Poggiale; he attributed this to his solutions being supersaturated.

He made a fresh series of determinations, allowing the hot saturated solutions to cool to 0° C. and then immersing them in ice for prolonged periods with frequent shaking, and found that after one hour the composition of the solution did not alter, even after standing for ten hours.

From this he concluded that supersaturation may be avoided by shaking for one hour at constant temperature. He repeated his previous work making use of this method.

* Pogg., 94, 255 *et seq.*

1872. *Page and Keightley*[47] found higher values for the solubility of sodium and potassium chlorides, nitrates, and sulphates when obtained by the method of cooling than when water was saturated with the salt at the required temperature.

In the same year *Oudemans*[48] lamented the discordance of many results recorded for the solubility of substances, and pointed out where many errors arose, particularly the difficulty in obtaining a perfectly saturated solution.

1875. To avoid supersaturation *Limpricht*[55] found it necessary to allow the solution to stand in a cellar for several weeks at constant temperature.

Victor Meyer[57] showed that the same end could be rapidly attained by placing a large test-tube containing a hot saturated solution in a bath and stirring until the solution and the bath were at the same temperature, allowing to stand for two hours and again stirring before filtering off a sample through a dry filter, the temperature being recorded.

The estimations were carried out by evaporating 10-30 c.cms. of solution.

He also described an apparatus[58] for enabling a solvent to be saturated and the solution filtered into a receiving vessel, the whole operation being carried out in the vapour of some constantly boiling liquid.

An exact method of determining solubility was next published by *Lajoux.*[62] The solvent was heated with the substance to the required temperature, and a portion of the solution taken by means of a jacketed syphon fitted with a filtering plug of cottonwool.

1879. *Koehler*[79] modified V. Meyer's apparatus, so that the whole operation, including filtration into an empty vessel, could be carried out beneath the surface of the liquid forming the bath.

1880. *Hannay and Hogarth*[80] used a modified form of Andrews' apparatus * for their work on the solubility of solids in gases.

1883. *De Coppet*[97] used a completely enclosed copper bath with glass windows on two sides, containing 18 litres of glycerine. The temperature was kept within ± 0°·1 C. by using the expansion of the entire mass of liquid in the bath as a thermoregulator. For temperatures below 0° saturated solutions of salts took the place of the glycerine. Nine boiling-tubes were hermetically fixed in the top of the bath, three of which were used to read its temperature. The remaining boiling-tubes were closed with corks through each of which passed (1) a thermometer, (2) a stirrer, (3) a short tube and rubber compression pear, (4) a syphon through which, by compressing the pear, a sample of clear solution was ejected without loss by evaporation.

The solutions were stirred for at least two hours before allowing to settle.

Nicol[98] described a bath and thermoregulator by means of which he reduced the temperature variation to 0°·05 at 20° C.

1884. For each determination[102] two boiling-tubes were used, containing salt and water and supersaturated solution respectively. After being stirred for twenty-four hours by a current of moist air, the

* Vide *Trans. Royal Soc.*, 1869, 159, 583.

tubes were closed by corks fitted with a short tube and a long syphon tube the end of which was covered with a piece of cambric to serve as a filter. After two hours, samples were ejected by blowing through the short tubes.

Tilden and Shenstone [103] determined the solubility of salts at high temperatures by enclosing salt and solvent in specially constructed metal tubes, which were heated to the requisite temperature for four to five hours whilst resting in a slightly inclined position. The end containing the solid was then gradually raised, causing the liquid to drain from the solid and collect at the other end of the tube.

In carrying out work at low temperatures *Étard* [107] employed methyl chloride for the bath. He always determined the solubility at the highest temperature the thermometer indicated, recognising that any lowering of the temperature would cause supersaturation.

1885. *Guthrie* [111] determined the solubility of salts in fused sodium nitrate by adding small quantities of the salt, the whole being well stirred until no more dissolved. The mass was then allowed to cool slowly to allow excess of added salt to separate out; then the liquid was poured on to a cold slab and analysed.

1886. At temperatures about 100° *Alexejeff* [118] sealed crystals in a tube with water and heated until almost all the crystals were dissolved. The tube was then cooled until the remaining crystals began to grow in size, the temperature at which this occurred being taken as the saturation temperature.

1889. For temperatures between 250°-450° *Étard* [143] used a bath of a fused mixture of sodium and potassium nitrates. Salt and water were sealed up in thick-walled glass tubes (7 mm. by 15 cm.), and the temperature was observed at which the last traces of salt disappeared.

1890. By means of an electrically arranged gas-cut-off *Meyerhoffer* [157] maintained the temperature of his thermostat to 0°·1; in this work the thermostat liquid was not stirred, but the solvent and solute were stirred together in a vessel supported in the middle of the bath. The saturated solution was taken up by means of a warmed Landolt pipette, and was analysed by titration.

Riecker and van Deventer [160] used Victor Meyer's method (*vide* this section, 1875), modified so that the entire operation, including taking the sample of saturated solution, was carried out under the surface of the thermostat liquid.

The saturated solutions employed by *Noyes* [164] were obtained by shaking the solvent with excess of solid for several days in a thermostat.

1893. *Kohlrausch and Rose* [204] calculated the solubility of very sparingly soluble salts from measurements of the electrical conductivity of the saturated solutions.

1894. When determining solubility at high temperatures *Étard* [214] used a glass tube bent to an angle of 120° and constricted at the middle. Salt and water were placed in one arm and the tube sealed. After heating at a fixed temperature the saturated solution was allowed to run into the other arm of the tube, and when cooled was analysed.

Goodwin [212] calculated the concentration of one ion in saturated

solutions of so-called insoluble salts from measurements of E.M.F.; and, assuming the salts to be completely ionised, he calculated their solubility.

II. B.—*Solubility of Liquids.*

Draper[67] determined the solubility of ether in solutions of hydrogen
1877. chloride by adding a given quantity of ether to a known volume of solvent in a graduated, stoppered tube. After shaking briskly at intervals for an hour at the required temperature in a bath, the two layers were allowed to separate and the volume of ether remaining undissolved was read off.

1878. This method was also employed by *Schuncke*[74], but the precaution was taken not to allow the excess of solute to be more than 0·3 cc.

1881. *Konowalow*[87] placed the two liquids in a tube and shook together in a bath at constant temperature; the resulting layers were analysed. Volatile liquids were sealed up in bulbs with tubes so that after saturation, the points of the tubes being broken, the two layers were collected separately as they flowed out.

1882. *Alexejeff*[95] weighed quantities of the two liquids into a tube which was then sealed up and heated until a homogeneous mixture was obtained. The tube and contents were then slowly cooled and the temperature indicated when turbidity first occurred was regarded as the temperature at which the liquids were mutually soluble.

1884. *Guthrie*[105] sealed up weighed quantities of tri-ethylamine and water in a graduated tube and estimated their mutual solubility by measuring the volumes of the two layers at different temperatures; also the temperature at which a homogeneous mixture resulted.

1890. For the method employed by *Doyer*[166], *vide* this Section C, 1890.

1895 *Bancroft*[229] investigated the miscibility of ternary mixtures by placing a certain quantity of one liquid in a test-tube and adding small quantities of the other two liquids from burettes until the mixture was homogeneous at a definite temperature.

II. C.—*Solubility of Gases.*

Bunsen's[19] specially constructed absorptometer admitted of a
1885. measure being made of the volume of gas dissolved by shaking together known volumes of gas and solvent over mercury in a eudiometer tube surrounded by water; the temperature of the water was read at the end of the experiment. The absorption coefficient of oxygen was found by passing a stream of air, free from ammonia and carbon dioxide, through water, analysing the gas expelled from the saturated solution, and from these data and the absorption coefficient of nitrogen, that of oxygen was calculated.

Carius[20] passed the dry gas through the solvent contained in a flask, through the cork of which passed a thermometer and two tubes dipping into the liquid, also a short tube to allow unabsorbed gas to escape.

The two long tubes were respectively used to admit gas and to syphon off samples of saturated solution.

In the case of the more soluble gases [20A] the specific gravity of the solution was determined and the expansion due to the absorbed gas allowed for. The gases were estimated by chemical methods.

Fernet [18] measured the volume of the gas to be dissolved over mercury in a eudiometer tube which was surrounded by water; the absorption was carried out in a separate vessel, also kept in a water-bath, and which could be connected with the eudiometer.

1856. When determining the solubility of ammonia *Carius* [23] passed the gas through water contained in a tube constricted and blown into a small bulb. At saturation, the bulb was closed by a rod ground to fit the constriction. The liquid above the constriction was then run out and the bulb dried and weighed. The volume of the bulb being known, the weight and specific gravity of the solution were simultaneously determined.

Roscoe [25] saturated water with a mixture of hydrogen and chlorine and compared the amount of chlorine dissolved with that which would have been dissolved if the gas absorbed was proportional to its partial pressure.

1859. *Roscoe and Dittmar* [29] used an absorption bulb having the inlet tube twice bent and joined to the bottom of the bulb, the outlet tube being joined to the top of the bulb; both tubes were constricted to facilitate sealing off. The bulb was half filled with water and immersed in a water-bath, and gas passed through, either under ordinary or under increased pressure. When saturation was reached the stream of gas was continued for thirty minutes, then the apparatus was closed by a rubber tubing and pinch-cocks, immersed in a freezing mixture, and sealed at the constrictions. After weighing, the contents of the bulb were analysed.

For determinations under reduced pressure a small flask with constricted neck was partially filled with a solution saturated at a lower temperature, and joined to a manometer tube dipping under mercury. By heating the bulb gas was expelled and displaced the air in the manometer. When sufficient gas had been driven off the flask was cooled and placed in water at the required temperature; the mercury rising in the manometer. When equilibrium was attained the pressure was observed and the flask sealed at the constriction.

These authors tried Carius' method (*vide* this Section 1856), but found that it gave low results owing to the solution being open to the air, so that the partial pressure of the gas was less than the atmospheric pressure.

1864. *Robinet* [35] determined the amount of gas in a liquid by boiling the liquid in a eudiometer tube over mercury and measuring the volume of the gas expelled.

1867. *Khanikof and Louguinine* [42] used Bunsen's method, so modified that the absorption tube could be rotated in a bath of water.

1874. When determining the solubility of ammonia in water *Raoult* [53] passed the gas through a known quantity of water contained in a flask; the out-flowing gas was passed through a U-tube, containing solid potash to retain water, and the absorption flask was placed in a well-stirred water-bath maintained at a constant temperature.

The apparatus was weighed before and after saturation, and the difference gave the amount of ammonia absorbed.

1876. *Setschenoff*[65] used a similar method to that of Fernet, but connected the measuring and absorption vessels by a flexible capillary of silver, so that the absorption bulb could be shaken without disconnecting it.

1877. *Mackenzie*[66] made use of an absorption tube divided into two parts by a stop-cock and immersed in water. The lower part was filled with solvent and the upper part with gas at the requisite pressure, which was measured by a separate manometer. The stop-cock was opened and the gas and solvent shaken together. The absorption tube was again joined to the manometer and mercury allowed to flow into the absorption tube until the original pressure was attained. These operations were repeated until no more mercury entered the absorption tube. The volume of mercury in the absorption tube, obtained by weighing the dry mercury, gave the volume of gas dissolved.

To expel the gas from a saturated solution and at the same time to measure its volume *Hüfner*[69] devised a special form of Sprengel pump.

1882. *Wroblewski*[91] described a form of absorptometer he used to measure absorption coefficients up to 60 atmospheres, the pressure being determined by means of an air-manometer.

1884. *Roozeboom*[110] passed hydrogen chloride gas into water at a temperature about 2° C. lower than the final temperature: the temperature was allowed to rise gradually and then maintained within 0°.1 C. for fifteen minutes.

1889. *Lubarsch*[148] used a modified form of Lunge's nitrometer to collect and measure the volume of gas expelled from saturated solutions by evacuation.

Pettersson[153] described an apparatus for boiling out and measuring the volume of a gas in solution. In the hands of *Pettersson and Sondén*[154] this apparatus gave very concordant results.

In passing gases through liquids, *Winkler*[156] measured the height of the level of solvent above the end of the inlet tube, and added half the pressure due to this height to the barometric pressure to obtain the partial pressure of the gas.

1890. *Timofejew*[163] gave a detailed description of the use of an apparatus similar to that employed by Fernet (*vide* this Section 1857).

Doyer[166] measured the quantity of dissolved substance carried out of solution by a known volume of air passed through the solution, and from this calculated the partial pressure corresponding to a given strength of solution. The absorption coefficients were found by this means for gases and also for substances which are liquid at ordinary temperatures.

1891. A differential absorption apparatus was described by *Bohr and Bock*,[167] in which the measurement of the partial pressure of the gas was directly determined, independent of the vapour pressure of the solvent. By this means absorption coefficients were obtained with increased accuracy up to 60° C.

1895. *Pryty and Holst*[231] passed carbon dioxide gas through, or added solid carbon dioxide to water contained in a flask. The

amount of gas in solution was found by weighing the whole and making a correction for the gas unabsorbed.

III. A.—*Physical Nature of Solvent.*

By far the major portion of the work published on the subject of solubility has reference to cases where water was the solvent used. More recently, however, it has been recognised that a true explanation of the phenomena of solubility will be more readily arrived at from a study of the behaviour of substances towards solvents in general rather than towards water or any other solvent in particular.

There can be little doubt that solubility phenomena involve the reciprocal interaction of solvent and solute, be such action physical, chemical, or physico-chemical in nature. For this reason an attempt has been made to classify under this section, A, work relating to the influence of the physical nature of the solvent, and B, the influence of the chemical nature of the solvent on the solubility of substances.

1802. *Dalton*[2] announced that the total pressure of a mixture of gases occupying a given space is the sum of the partial pressures exerted by the constituents of the mixture. This means the solubility

1876. of a gas in another gas becomes simply a question of admixture.

1879. Some deviations from this were, however, observed by *Andrews*[63] and also by *Regnault*.[76]

The phenomenon of a solid dissolving in a gas was examined by *Hannay and Hogarth*[75]; they employed the sulphur halides as solutes and the solvents used were alcohol, ether, carbon bisulphide, &c., kept well above their critical temperatures.

1880. They carried this work further,[80] making use of potassium iodide and cobaltous chloride dissolved in alcohol vapour at 300-320° C. From their results it appeared that the absorption spectrum of a substance dissolved in a gas was practically identical with the absorption spectrum of that substance when dissolved in the liquefied gas.

Although *Ramsay*[81] threw doubt upon this work, suggesting that these authors had merely observed the phenomenon of solubility of a solid in a hot liquid, the observations were substantiated by *Lenier*.[82]

The behaviour of partially miscible liquids was most thoroughly

1881. investigated by *Konowalow*,[87] the work embracing the influence of pressure and temperature on the mutual solubility of water and respectively formic acid, propylic alcohol, methylic alcohol, and ethylic alcohol. Similar work on the solubility of one liquid in another

1886. (mutual solubility) was carried out by *Alexejeff*,[118] who found the solubility varied with the cohesion: the greater the cohesion, the greater the solubility.

1888. *Carnelley and Thomson*[136] found a parallel relationship existed between the solubility of acids and of their salts which was not disturbed by varying the nature of the solvent employed; further, that the ratios of the solubilities of two organic isomerides in any solvent is very nearly constant, and is therefore independent of the nature of the solvent used.

With certain solvents *Alexejeff*[118] had previously recorded that

solutions of organic compounds sometimes separate into two layers of
1889. different concentration; these cases formed the subject of a theoretical discussion by *Roozeboom*.[141]

1890. *Walker*[158] deduced a relation between the solubility of a substance in any solvent and its heat of fusion.

1892. A comparison of the graphs which represent the solubility of naphthalene, triphenylmethane, diphenylamine, and phthalic anhydride in carbon bisulphide, in hexane, and in chloroform enabled *Étard*[200] to conclude that the lower the melting-point of the solvent the greater the solubility of a substance therein at any common temperature. His measurements of the solubility of naphthalene in carbon bisulphide at temperatures approaching the melting-point of this solvent show that at that temperature (– 115°) the solubility will become zero. He showed the melting-point of the solvent was the inferior limit of solubility.

Winkler[190] traced an empirical connection between the diminution of the absorption coefficient of a gas brought about by a rise of tempera-
1894. ture and the corresponding decrease in the viscosity coefficient of the solvent *Thorp and Rodger*[216] criticised this conclusion, and from their discussion of the subject it would appear that for the same gas the diminution in the absorption coefficient for any temperature interval is approximately proportional to the corresponding diminution in the viscosity coefficient of the solvent.

As indicating the part played by the solvent in conditioning the
1895. dissolution of a substance, mention must be made of *Pictet's*[230] observations on the volatility of otherwise non-volatile substances when dissolved in volatile liquids. At ordinary pressures borneol is not volatile in ether vapour, but when heated with ether to a temperature below its melting-point it was found to be completely volatile.

This and other similar results obtained with borneol and ethyl chloride, and with ether as solvent for guaiacol, iodine, or phenol, appear to support the contention of Hannay and Hogarth that solids dissolve in vapours.

III. B.—*Chemical Nature of Solvent.*

1854. *Kremers*[17] made numerous solubility measurements with the object of finding some existing relationship between the solubility, nature of solvent, and the nature of the solute, but no statement of general application was possible.

1876. The absorption coefficient of carbon dioxide in pure sulphuric acid was found by *Setschenoff*[65] to be the same as in water, but the addition of water caused this value to decrease rapidly to a minimum.

Bunsen * showed, in the case of alcohol and water, there was apparently no relationship between the solubility of a gas and the
1887. nature of the solvent, a conclusion confirmed by *Gniewosz and Walfisz*.[130]

1889. *Woukoloff*[147] adversely criticised the conclusions arrived at by Louguinine, Khanikoff, and Wroblewski, namely, that the

* *Vide* Section IV. B, 1855.

absorption of carbon dioxide in water does not take place in accordance with Dalton's law.

He pointed out that in this case chemical action probably takes place between solute and solvent.

Determinations of the solubility of carbon dioxide in carbon bisulphide at various temperatures show an approximation to Dalton's law. He published later[150] the results of determinations made in chloroform.

1892. An important paper by *Étard*[186] furnished an interesting comparison of the behaviour of mercuric and cupric chlorides in various organic solvents; the solubility results were plotted as functions of temperature; the observations ranged from -60° to $+210^\circ$. The solvents employed were water, methylic alcohol, ethylic alcohol, propylic alcohol, *iso*-butylic alcohol, acetone, acetic acid, ethylic acetate, ether, and ethylic formate.

Great similarity was observed in all parts of the graphs representing the results obtained with water, methylic and ethylic alcohols, the graphs for *n*-propylic alcohol and *iso*-butylic alcohol only being similar to the foregoing alcohols in the region representing temperatures above 40°.

With the exception of ether, ethylic formate, and ethylic acetate, all the graphs show distinct points of flexure when mercuric chloride is the solute, but with cupric chloride the graphs appear as straight lines.

Lobry de Bruyn[199] found that with hydrated magnesium sulphate and zinc sulphate, methylic alcohol as a solvent lies between water and ethylic alcohol. Similar results to this were found by *Delépine*[191] in the case where ammonia was the solute, the coefficient of solubility at 0° being for ethylic alcohol 209, for methylic alcohol 425, and for water 899.*

1894. Mention must be made of *Steiner's*[219] work on the solubility of hydrogen in aqueous sugar and salt solutions. It is significant that the salts giving greatest molecular effect in the more dilute solutions are sodium sulphate, magnesium sulphate, calcium chloride, aluminium chloride, and potassium carbonate, all of which decrease rapidly in action as their concentration is increased. Salts which produce smaller molecular lowering of the solubility coefficient of hydrogen are sodium chloride, potassium nitrate, potassium chloride, lithium chloride, sodium nitrate, and also cane sugar; all these decrease but slightly as their concentration is increased.

IV. A.—*Nature of the Solute—Physical.*

Like his attempts to establish some relationship between the solubility of a substance and its nature with the nature of the solute (*vide* Section III. B), *Kremers'* endeavours to trace a connection between the atomic volume of the solute and its solubility were unsuccessful.

1854.

1868. *Von Hauer*[44] considered the study of solubility afforded a means of determining the isomorphous nature of salts with considerable accuracy.

* This value is given by Sims, *Ann. d. Pharm.*, **118**, 345.

1875. The observations of *Boisbaudran*[59] on the unequal growth of crystal facets when a crystal is kept for a long time in a solution slightly supersaturated, have considerable bearing upon the subject of the physical nature of a substance influencing its solubility. Observations of a similar nature were made by *Pfaundler*,[56] who explained the phenomenon of a crystal changing shape and not weight by a difference in the energy of vibration on the various crystal facets.

1882. *Carnelley*[88] traced the influence exerted on the solubility by the atomic arrangement of isomeric carbon compounds (the substance of lower m.p. being considered to be less symmetrical), and came to the conclusion that the isomeride of less symmetrical molecular structure was the more soluble. Examples of compounds of equal molecular symmetry having identical solubility were furnished by the researches
1884. of *Leidie*[90] on the solubility of the tartaric acids; whilst *Tilden*[101] established a similar relationship among inorganic compounds to that found by Carnelley—namely, that with isomorphous salts the most soluble was also the most fusible.

A relation between molecular volume and solubility was observed by *Nicol*,[102] who adduced instances to show that a diminished molecular volume is attended by a diminished solubility.

With the object of ascertaining whether the state of aggregation of
1886. a substance in any way affected its solubility, *Alexejeff*[118] determined the solubility of solid and liquid salicylic acid at one and the same temperature. In the liquid state this acid was found to be more soluble, as also was liquid benzoic acid more soluble than the solid at the same temperature—results quite contrary to the views expressed by Gay-Lussac. He also found the solubility of a hydrate was always greater than that of the anhydrous substance.

1887. Bodies having similar melting-points were stated by *Schröder*[131] to have very similar molecular solubilities; and he used this relationship for calculating from published data the molecular solubility of a series of inorganic sulphates, and also of their double salts with ammonium sulphate.

When studying the conditions of equilibrium between a salt and water, Alexejeff (1886) noted the disturbing effect of the solution separat-
1889. ing into two layers of different concentration. This question was theoretically discussed by *Roozeboom*,[141] but his conclusions were unsupported by any experimental evidence.

Walker[158] applied the thermodynamic equation $dp/dt = C/Tv$, and
1890. the gas equation $pv = Rt$, to solutions, and deduced a relationship between the solubility of a substance in any solvent and its heat of fusion; it was supported by experiments with *p*-toluidine dissolved in water.

Assuming the latent heat of solution of a substance to be equal to
1894. its latent heat of fusion, *Le Chatelier*[221] showed the following relationship may be developed from established law of solution:—

$$0{\cdot}002 \log S - \frac{L}{t} + \frac{L}{t_0} = 0$$

in which S=mol. conc. of diss. sub., L=latent heat of fusion, t_0=the m.p. of diss. sub., t=the solidifying pt. of the solution.

As will be seen, this equation contains no term relating to the solvent, and the author concludes that the curve of solubility of a given substance is independent of the nature of the solvent. This prediction was supported by determinations of the solubility of salts one in another, salts being chosen which form neither isomorphous mixtures nor combine to form double compounds.

In support of Walker's conclusion that a substance in the liquid state when at a temperature below its m.p. would be more soluble than
1895. the solid at the same temperature, *Bruner's* [233] results may be quoted. He found the solubility of supercooled sodium thiosulphate in aqueous alcohol was much greater than the solid at the same temperature.

IV. B.—*Nature of the Solute—Chemical.*

The earliest observation on the relation between the nature of the
1855. solute and its solubility appears to be due to *Bunsen* [19], who stated as a conclusion from his work on the absorption of gases that the absorption coefficient is dependent upon the nature of the gas.
1872. This was followed some time afterwards by *Berthelot and Jungfleisch's* [49] statement of a relationship they found between the coefficient of distribution (*vide* Section VI.) and the chemical composition of the dissolved substance. These authors remark how ether more readily removes from aqueous solution (1) the more highly carburetted of two homologous acids; (2) monobasic rather than dibasic acids of nearly the same percentage composition; (3) the compound containing least oxygen of acids which contain the same number of carbon and hydrogen atoms.

An interesting comparison of the solubility at 0° C. of benzoic acid,
1878. salicylic acid, oxybenzoic acid, and *p*-oxybenzoic acid was made by *Ost*,[72] but no definite conclusions could be arrived at.

In the same year *Bourgoin* [73] traced the solubility-temperature curves of benzoic and salicylic acids; below 40° C. salicylic acid was found to be less soluble and above 40° C. more soluble than benzoic acid.
1882. A large number of isomeric carbon compounds were examined by *Carnelley*,[88] who endeavoured to ascertain whether any relationship existed between the solubility and the constitution of organic compounds (*vide* Section IV. A). Those possessed of greatest atomic symmetry were found to be most soluble.
1883. A conclusion similar to this was arrived at by *Tilden* [99] from a study of the melting-point and solubility of various inorganic salts. Further work by Tilden [101] extended this rule to isomorphous hydrated salts having the same amount of water of crystallisation, in which case it was found that the order of solubility and fusibility of such salts was the same at all temperatures below the point of fusion or dissociation of the hydrate.

The observation of *Nicol* [102] on the relation between molecular volume of a salt and its solubility (*vide* Section VII., 1883) was found by him to hold whether the composition of the salt remained unchanged or not.

1885. An examination of the solubility of the acids of the oxalic series was carried out by *Henry*, [111] who observed an alternating variation in solubility; acids containing an even number of carbon atoms being far less soluble than those containing an odd number of carbon atoms.* When classified in this manner it was noticed that each group of acids showed a diminishing solubility as the molecular weight increased.

An investigation by *Raupenstrauch* [113] of the solubility of the silver salts of various acids of the acetic series led this author to the conclusion that the solubility in general, as also the increase in solubility with rise of temperature, is always greater for the lower members of a homologous series. The salt of an *iso*-acid was found to be more soluble than the same salt of the *normal* acid, although no general rule could be framed.

1886. These results were, in the main, substantiated by a similar research with salts of acids of the oxalic series carried out by *Miczynski* [119].

1887. *Sedlitzky* [132] studied the solubility of various salts of acids of similar constitution—namely, *iso*-valeric, methylethylacetic, and *iso*-butyric acids—but was unsuccessful in discerning any connection between solubility and constitution.

1888. Further evidence was published by *Carnelley and Thomson*[136] in support of the connection previously discovered by them between solubility and fusibility (regarded as indicative of molecular symmetry).† They found this relationship existed not only among isomeric acids, but, with few exceptions, could be extended to their salts; the general rule being that salts of the more soluble and more fusible acids are also more soluble than the corresponding salts of the less fusible and less soluble acids.

1890. An important paper by *Doyer* [166] contains results of measurements of solubility coefficients of ammonia and also of the amines. The values for the amines show an apparent lack of agreement; however, this discordancy is noticed in their other physical constants, notably in the vapour tension measurements:—

	Solub. Coeff.		Vap. tens.
NH_3	386	NH_3	53·7
$CH_3\,NH_2$	511	$CH_3\,NH_2$	40·7
$(CH_3)_2\,NH$	230	$(CH_3)_2\,NH$	90·3

1892. *Roozeboom* [198] discussed the solubility curves of salt pairs which form double salts and mixed crystals—more especially for ammonium chloride and ferric chloride.

It had been previously stated by Le Chatelier that of two hydrated forms of a substance, the one containing less water is more soluble in water than the more highly hydrated form. This rule was called into question by *Kurnakoff*, [194] who cited several exceptions, notably

* In 1877 Baeyer noticed a similar relationship between the melting-points of the acids of this series, those containing even numbers of carbon atoms having higher melting-points than those with an odd number, the melting-point of the former decreasing, of the latter increasing, with increase in molecular weight.

† *Vide* Section IV. A.

amongst the ammonio-metallic compounds (chlorides and nitrates of the roseopentamine bases)—where the compounds $MX_3,5NH_3,H_2O$ are much more soluble than the corresponding anhydrous salts MX_3, $5NH_3$.

He also made mention of the fact that organic anhydrides, lactones, oxides, &c., are less soluble than the hydrated compounds.

Other instances of the chemical constitution of a substance influencing its solubility may be seen from a comparison of the solubility
1894. of the calcium, barium, and silver salts of the fatty acids. In this connection *Lieben* [220] found certain fixed relations between the constitution of the acids and the solubility of their salts.

For the normal acids the relationship is simple; each substitution of a methyl group for hydrogen producing a regular change in the solubility of the salt. In the cases of acids other than normal, although undoubtedly existing, the connection between constitution and solubility is not evident.

1895. From a study of the solubility of various benzene derivatives in water, *Vaubel* [235] concluded the solubility of these substances is primarily conditioned by the presence of an amido-, hydroxyl-, or carboxyl- group. He also observed that the dissolution tendency of these groups is weakened by such substituents as the methyl, bromine, iodine, or nitro groups.

In the case of isomeric derivatives the *meta*- substituted compound has greatest and the *para*- substituted compound the least solubility. Carnelley and Thomson's rule that for isomeric organic compounds the order of solubility is the same as the order of fusibility does not hold.

V. A (i)—*Solubility in relation to Temperature.*

The fact that change of temperature influenced the solubility of most substances was an early discovery, but probably the first accurate study
1819. of this phenomenon is to be found in a memoir by *Gay-Lussac.* [5] To this worker is also to be attributed the formula expressing the solubility of salts where the increase of solubility is proportional to the temperature. In those cases where this proportionality did not exist
1840. *Kopp* [10] arrived at a mathematical expression connecting solubility and temperature. He also extended his work to cases where the solubility of a salt was influenced by the presence of another salt, with like base, and also with like acid—namely, KNO_3 with K_2SO_4, &c., and KCl with $BaCl_2$, &c. This was followed by an extensive investigation
1843. by *Poggiale,* [12] who determined the solubility of sixteen salts at intervals of 10° C.; from his results, however, no general conclusion could be drawn.

1855. *Bunsen* [19] studied the absorption of gases in liquids, and introduced the term 'absorption coefficient' as indicating the volume of gas, reduced to 0° and 760 mm., which is absorbed by unit volume of a liquid at normal temperature and pressure. He showed the absorption coefficient was independent of pressure, but (except in some cases, as hydrogen, oxygen, and carbon dioxide) depends upon temperature and the nature of the gas.*

* This work was carried further by Carius, who studied the absorption of

1856. *Kremers*[21], [22] continued work on the solubility of salts. In
1857. the following year a memoir was published by *Abascheff*[27] on the solubility of one liquid in another; he was probably the first to ascertain that liquids only partly miscible at ordinary temperatures are often completely miscible at higher temperatures.

1861. *Sims*[31] examined the absorption of ammonia in water (*vide* Section V. B) at various temperatures, and found that with rising temperature the absorption more nearly approached the requirements of Henry's law. Contrary to the conclusion of Schönfield,* he also showed that sulphur dioxide only obeyed this law above 40°. Following the systematic study of solubility of salts in water carried out by
1864. *Alluard*[36] and by *Mulder*,[37] the above observations made by Sims were supported by the results obtained by *Watts*.[38] A general
1865. expression connecting solubility and temperature was proposed
1869. by *Nordenskjöld*,[46] who observed how the solubility generally increased disproportionately with the temperature; increasing more rapidly.

Among other complicated relations between solubility and tempera-
1875. ture *Alexejeff*[54] found the solubility of amylic alcohol in water decreased with rise of temperature, while that of water in amylic alcohol increased with rise of temperature.

Setschenoff[46A] reinvestigated the solubility of gases in liquids, and obtained results which were not in agreement with those recorded by
1880. Bunsen; additional doubt was thrown upon those long recognised values by *Naccari and Pagliani*.[83]

1881. Previous to the work of *Precht* and *Wittjen*[85] the solubility of salt mixtures had been studied at only a small range of temperature.† These investigators found, among other interesting points, that between 10° and 100° C. the solubility of KCl in presence of K_2SO_4 in water was practically the same as in pure water. In dilute solutions of NaCl the solubility of $BaCl_2$, although somewhat depressed, increased with rise of temperature at almost the same rate as it does in water only.
1882. Their continuation of this work,[91] using mixtures of salts such as occasion double salt formation, gave results difficult to interpret.

Determinations of the solubility of calcium butyrate in water at various temperatures were made by *Hecht*.[92] His results showed a solubility decrease as the temperature rose from 0° to 65°, between 65° and 80° the solubility was constant, and from 80° to 100° it slowly increased with rise of temperature.

Goodwin[93] studied the influence of certain metallic chlorides on the solubility of chlorine at various temperatures. *Wroblewski*[94] measured the absorption of gases by liquids at high temperatures. Later on
1883. *de Coppet*,[97] who experimented on the lines of Gay-Lussac, but employed more delicate means of maintaining a constant temperature, was led to the conclusion that when solubility values are

ammonia in water (*Ann. Ch. Pharm.*, 1856, 99, 129, and also by others, *vide* footnote Section V. A, 1890).

* *Ann.*, 1854, **95**, 1.

† 1879. J. Schönach[77] studied solution of NaCl with KCl at temperatures from 0° to 100°, but could obtain no simple mathematical relationship. *Vide* Section V. C (iii).

plotted against temperature intervals, anhydrous salts give straight lines while substances which combine with water do not.

The trend of such solubility temperature curves was followed beyond the usual temperature of experiment by *Tilden and Shenstone*,[99] who obtained distinct indication of a relationship between the solubility and the fusibility of substances.

1884. Further work by *these authors* [103] established the fact that the rate of increase of solubility at temperatures above 100° follows the order of the melting-points of the substances in question.

Guthrie [106] made use of these results, supplemented by his own observations, in considering the question of infinite solubility, and gave experimental evidence for such a state of things as a finite quantity of water dissolving an infinite quantity of salt. He was the first to observe the continuity of the solubility curve up to the melting-point of potassium nitrate.

Étard [107] determined the solubility of the halogen salts of calcium, strontium, barium, and several other metals between the freezing-points of their solutions and 180°. He found the temperature curves were always straight lines for a certain temperature interval (when solid salt is referred to total liquid and not to water), and he regarded that straight portion as indicating the normal solubility curve. Inflections in such curves were considered as being due to a change of 'state of hydration' of the salt, and not as representing the true solubility curve. All the salts employed gave solubility values which were proportional to the temperature.

These conclusions were confirmed in a further publication,[107] in which it was stated that in order to describe the solubility of a salt it was sufficient to give a point on the curve of deviation and to express the straight portion of the graph in terms of the equation $S=a+bt$, in which S=solubility, t=temperature, and a and b are constants. A third communication in the same year supported this opinion and gave constants for various salts.

1884. *Chancel and Parmentier* [109] found the solubility of carbon bisulphide in water rapidly diminished as the temperature rose, becoming *nil* at the boiling-point of carbon bisulphide, the behaviour under change of temperature being that of a substance which forms no chemical combination with the water.

1885. A year later they found [109] that chloroform increased in solubility from 0° to 30°, and decreased from 30° to 55° C.

The solubility of certain salts in fused sodium nitrate (*vide Guthrie* (sen.) [106]) was further investigated by *F. B. Guthrie*, who found that the higher the temperature the greater the proportion of salt entering into fusion.

A study of the relation between temperature and solubility of sparingly soluble substances led *Le Chatelier* [112] to important conclusions as to the thermodynamics of solution phenomena (*vide* Section V. A (ii).

In the same year *Raupenstrauch* [113] made a study of the solubility of the silver salts of various acids of the acetic series, and arrived at interesting conclusions regarding the constitution of salts and their

1886. solubility. The salts of the oxalic acid series were investigated from this point of view by *Miczynski*.[119]

The solubility of one liquid in another was studied by *Alexejeff*,[118] who found a regular increase in solubility with rise of temperature, provided always that no combination takes place between the two liquids, otherwise no such regularity was observed. He studied more particularly the increase in the mutual solubility of phenol and water as the temperature was raised to the point of complete miscibility.

1887. *Sedlitzky*[132] deduced from his own observations mathematical expressions connecting temperature and solubility for various salts of *iso*-valeric, methylethylicacetic and *iso*-butyric acids.

A further publication by *Étard*[128] was in substantiation of his
1888. solubility formula, and contained constants for copper sulphate solubility graphs. This investigator[137] found that above 103° up to 190° the solubilities of most sulphates decrease with rise of temperature; a similar decrease was also observed with salts of carbonic, sulphurous, and succinic acids, but not with salts of monobasic acids, except those of feeble organic acids.

Roozeboom[138] discussed the influence of temperature on the solubility of double salts, and, in the following year, the solubility of
1889. hydrated salts in relation to temperature.[140] His conclusions in the latter case were adversely criticised by *Le Chatelier*,[146] who could not agree with hydrated calcium chloride ($CaCl_2$, $6H_2O$) having two different coefficients of solubility at the same temperature. When the solubility results were plotted this author found two distinct curves meeting at the melting-point of the hydrate ($CaCl_2$, $6H_2O$), one being the solubility curve of the hexahydrate in water, the other that of the anhydrous salt in the solution of hexahydrate.

The relation between solubility of salts and their melting-points next engaged the attention of *Étard*,[143] who found with many salts an increasing solubility with rise of temperature up to the melting-point of the anhydrous salt; beyond this point a given quantity of water was considered capable of dissolving an unlimited quantity of salt. Shortly afterwards he obtained similar results[151] calculated from measurements of simultaneous solubility of sodium and potassium chlorides. The sum of the salts dissolved between $-20°$ C. and $+180°$ C. being represented by a straight line $Y{}^{+180}_{-20} = 27{\cdot}0 + 0{\cdot}0962t$, it was calculated that the temperature at the limit of solubility, or limiting temperature—*i.e.*, the point where the amount of water has become reduced to zero—is 738°, which is, curiously enough, approximately the melting-point of potassium chloride. A confirmation of this was next published[152] together with the calculated composition of the salt mixture (NaCl and KCl) at 738°.

1890. In a similar manner,[161] calculating from the graphs representing the solubility of potassium iodide in water, the limiting temperature was found by extrapolation to be 637°, practically the melting-point of potassium iodide (639°). When potassium bromide is added to the solution of potassium iodide the sum of the two salts in solution is equal to that of pure potassium iodide at the same temperature, and

at 637° it consists of a mixture of two-thirds potassium iodide and one-third potassium bromide. In a similar manner the sum of the solubility of potassium iodide and potassium chloride equals that of potassium iodide alone, and at 638° the mixture consists of 80 per cent. potassium iodide and 20 per cent. potassium chloride. Potassium bromide and potassium chloride in presence of each other show a similar behaviour.

From a study of the solubility of cupric chloride potassium chloride
1890. compounds *Meyerhoffer* [157] concluded that each individual substance has a definite solubility temperature curve; the change of solubility at the transformation point is considered to be due to the disappearance of that individual substance from solution, of which the curve becomes changed. *Roozeboom* [159] examined the solubility and transition points of the hydrates of thorium sulphate.

It has been already mentioned that more recent work * had thrown doubt on the values obtained by *Bunsen and his pupils* † for the absorption of gases by liquids; this prompted *Timofejew* [163] to re-investigate the relation between the solubility coefficients of oxygen, hydrogen, and carbon dioxide, &c., in water, also in alcohol, and the temperature, and, contrary to the observations of Bunsen and Carius, evidence was obtained of a temperature coefficient for these gases.

The solubility of hydrogen in water at temperatures between 0° and
1891. 50° was determined by *Winkler* [168]: the values found were in close agreement with those published by Timofejew. It was also observed that the absorption coefficient of hydrogen decreased with rise of temperature. A little later *Bohr and Bock* [167] published fresh determinations of the solubility of oxygen, hydrogen, and nitrogen in water, together with a further verification of the statement that the solubility coefficient of hydrogen was not independent of the temperature.

This was followed by another paper by *Winkler*,[168] in which he gave in tabular form the found solubility values for nitrogen and oxygen in water at temperatures ranging from 0° to 80°, and the calculated values between 80° and 100°, the results here recorded for nitrogen being considerably larger than those given by Bunsen.

With the object of gaining some knowledge of the state of salts in solution *Étard* [173] not only followed the change of solubility as the temperature rose, but also the alteration of colour of the variously coloured hydrated compounds of cobalt iodide and chloride; although of considerable interest, no conclusions of a general character were possible.

1892. In a paper, entitled 'Theory of Solubility Curves,' *Van Deventer and Van d. Stadt* [187] discussed how far it is possible to deduce a general law connecting solubility and temperature. They discussed the differential equations given by Le Chatelier and Van't

* *Vide* this Section, 1875-89.

† In a paper on the absorbing power of water for gases of the atmosphere (Pettersson and Sondén, *Ber.* 1889, 22, 1439) is to be found a fairly complete record of the work of Bunsen and his pupils on this subject.

Hoff, and showed that they are valid for sparingly soluble substances; also that *Roozeboom's*[140] equation holds for the more soluble salts.

From his own experiments on the absorption of various gases in water, *Winkler*[190] found the percentage decrease in the absorption coefficient between 0° and 20° was approximately proportional to the cube root of the molecular weight of the gas.*

Rise of temperature was found by *Delépine*[191] to cause a decrease in the absorption coefficient of ammonia in methylic and in ethylic alcohols.

Étard[186] found that the solubility temperature graphs for mercuric chloride in water, methylic alcohol, ethylic alcohol, and propylic alcohol all tend to meet at 265°, the melting-point of mercuric chloride.

Making use of the method of least squares, *Henrich*[193] recalculated from Bunsen's data the temperature equations for the absorption coefficients of gases.

Roozeboom[198] discussed the solubility temperature curves of salt pairs which form double salts and mixed crystals, more especially for ammonium and ferric chlorides. The isothermal obtained in this case is in accord with the requirements of Gibb's phase rule, and renders possible a general survey of the form of the solubility isothermals.

This communication was followed by an account of a careful study of the solubility of ferric chloride in water over a wide range of temperature. The graph representing his results shows four temperature maxima, which correspond to the hydrates $X,4H_2O$; $X,5H_2O$; $X,7H_2O$; and $X,12H_2O$.

Étard[200] determined the solubility of naphthalene triphenylmethane, diphenylamine, and phthalic anhydride in carbon bisulphide, hexane, and chloroform over the range of temperature from $-60°$ to $+90°$. He found the inferior limit of solubility of a substance was the melting-point of the solvent.

Results of a somewhat similar nature to the above were obtained by
1893. *Schröder*.[202] This worker made use of *p*-dibrombenzene dissolved in carbon bisulphide, benzene, monobrombenzene and in ether: naphthalene dissolved in benzene, chlorobenzene, and in carbontetrachloride: and also *m*-dinitrobenzene dissolved in benzene, brombenzene, and in chloroform. He concluded that the solubility of various solids in different liquids is the same at temperatures equally removed from the melting-point of the solid solute.

The solubility temperature curve of a substance is once again held by *Étard*[205] to represent the locus of the melting-point of mixtures of the dissolved substance and the solvent. True solubilities are said to be expressed as the amount of solute contained in 100 parts of saturated solution, and not the amount which is dissolved in 100 parts of solvent.

1894. In the case of ether and water a curious temperature influence was observed by *Schuncke*[218]: the solubility of ether in water being found to be largely influenced by change of temperature, whereas in the case of water dissolving in ether the temperature influence was practically *nil*.

He also found the absorption of gaseous hydrogen chloride by ether

* This was adversely criticised by *Thorp and Rodger*.[216]

above 0° to be a linear function of the temperature; below this it was not so: on the other hand, the solubility of ether in aqueous hydrogen chloride is approximately inversely proportional to the temperature.

Arctowski [209] determined the solubility of mercuric halides in carbon bisulphide over the range of temperature from -10° to $+30^\circ$. The solubility temperature curve in each case consisted of two straight lines, the points of change of direction in these graphs lie on a straight line.

The solubility of the iodide was found to be greater than that of the bromide, and increases at a greater rate as the temperature is raised: the same is true of the bromide as compared with the chloride.

A further communication [210] contained values for the solubility of iodine in carbon bisulphide between -94° and $+42^\circ$ C.; the graph in this case being composed of no fewer than six straight lines connected by short curves.

Although nothing very definite can be gleaned from *Roelofsen's* [213] measurements of the solubility of potassium hydrogen tartrate in various strengths of aqueous alcohol, it is of interest to find that as the concentration of the alcohol becomes greater the solubility of the tartrate is less increased by rise of temperature: in 90 per cent. aqueous alcohol a rise of temperature causes a decrease in the solubility of the tartrate.

Étard [214] published a complete summary of his more recent work on solubility, and included the results of determinations of the solubility of sulphur in carbon bisulphide, benzene, ethylene dibromide, and in hexane. Except in the last-mentioned solvent, the range of temperature was from the freezing-point of the solvent to the melting-point of the solute.

Later on he recorded [215] the limit of solubility temperature for various salt mixtures: that found for $AgNO_3 + KNO_3 = 198^\circ$ (the melting-point of $AgNO_3$); for $Ba(NO_3)_2 + BaCl_2 = 474^\circ$ (the melting-point of $Ba(NO_3)_2$; and several others. The composition of the salt mixtures at these temperatures was also given.

Étard's previous work on solubility of substances in carbon bisul-
1895. phide at low temperatures was called into question by *Arctowski*.[234] The solubility was not found to become zero at the freezing-point of the solvent; neither were the solubility temperature graphs found to tend to cut the temperature axis, but were asymptotic with it.

It had been independently shown by *Schröder* [202] and by *Le Chatelier* [221] that the solubility of a substance could be calculated from certain mathematical expressions.

In the light of this relationship *Linebarger* [237] discussed data for the solubility of inorganic salts in normal organic liquids, but could not recognise the applicability of the expression above referred to. The substances he used were mercuric chloride and cupric chloride dissolved in ethereal salts, mercuric halides in carbon bisulphide, and mercuric chloride, cadmium iodide, and silver nitrate in benzene.

V. A. (ii).—*Solubility in relation to Heat of Dissolution.*

Le Chatelier[112] published a mathematical application of the laws
1885. of chemical equilibrium to the case of the dissolution of salts in water. He showed the relation between the coefficient of solubility of salts, their heat of dissolution at point of saturation, and the temperature could be approximately expressed by an equation. This conclusion was extended,[112] and he formulated the general law that the solubility of a substance increases with rise of temperature when the heat of solution is negative, and *vice versâ*.

Chancel and Parmentier[127] took exception to this law, not
1887. considering it to be of general applicability in view of their observations on the relation between the solubility of normal calcium butyrate and calcium *iso*-butyrate at different temperatures and the thermal behaviour of these substances on dissolution. In reply to this criticism *Le Chatelier*[129] pointed out that the last-mentioned investigators had not measured the heat of dissolution in a saturated solution but in dilute solution; by direct experiment he proved the heat of solution of hydrated calcium *iso*-butyrate in saturated solution to be positive, as is required by his law of equilibrium. This brought a reply from *Chancel and Parmentier.*[127]

In a publication entitled 'Deductions from Van't Hoff's Theory'
1889. is to be found a discussion by *Pagliani*[155] of an expression for finding the heat of solution of a gas.

1890. *Riecker and Van Deventer*[160] found the solubility of copper chloride increased with rise of temperature, although this salt dissolves in much water with development of heat; in more concentrated solutions, however, this process of dissolution is endothermic.

1891. A comparison of solubility and heat of dissolution led *Timofejew*[171] to conclude that the molecular solubility of such substances as oxalic, succinic, benzoic, cinnamic, and salicylic acids in methylic, ethylic, and propylic alcohols varies inversely as the heat of solution.

This was also found[171] to be the case with cadmium iodide, mercuric chloride, and naphthalene in the same three alcohols. The ratio of the heat of dissolution of one and the same substance in methylic alcohol to its heat of dissolution in ethylic alcohol was found to be practically identical with this ratio when ethylic alcohol and propylic alcohol were the solvents employed.

The supposed general law enunciated by Le Chatelier, connecting
1892. variation in solubility with heat of solution, was shown by *Van Deventer and Van d. Stadt*[187] to be of only limited applicability.

Some interesting experiments were carried out by *Pickering*[189] on the relationship between solubility, heat of vaporisation, and heat of dissolution. Liquid substances of known heat of vaporisation were dissolved separately in water, acetic acid and benzene, and their heat of dissolution calculated.

1894. This author published[222] determinations of the heat of solution of calcium chloride; the results were plotted as percentage of $CaCl_2$ against molecular heat of solution.

Van Laar[224] contributed a mathematical paper containing calculations relating to change of solubility, heat of solution, &c.

V. B.—*Influence of Pressure.*

From observations made on the solubility of the permanent gases
1803. in liquids, *Henry*[3] formulated the law that the solubility of a gas
1807. in any liquid is proportional to the pressure of the gas used.*
In a publication entitled 'Heat Disengaged in Chemical and
1854. Molecular Attraction' *Favre and Silberman*[16] express the opinion that pressure only influences the solubility of a substance by virtue of an accompanying rise of temperature. The opinion expressed by Carius that Henry's law held good for the absorption of ammonia in
1859. water was disproved by *Roscoë and Dittmar*,[29] who showed this process to be far more complicated than was supposed.

1861. *Moller*[30] showed change of pressure influenced solubility quite independently of any accompanying temperature change. He found the solubility of sodium chloride and potassium sulphate increased with increase of pressure, while sodium sulphate decreased in solubility as the pressure was increased. These results were verified
1863. by *Sorby*,[33] who went further by showing a connection between change of solubility by pressure and change of volume when the salt separated from solution. If the solution of a substance is accompanied by expansion, and the separation of the same from solution by contraction, as in the case of ammonium chloride, then the solubility of that substance is decreased by pressure. Conversely, if, like sodium chloride or copper sulphate, solution is attended by volume contraction, the solubility is increased by pressure.

1867. *Khanikof and Louguinine*[41] carried out measurements of gas absorption as a continuation of Bunsen's researches, and considered that the results were incompatible with Henry's law.
1869. *Sims*[45] recorded experiments on the absorption of ammonia and sulphur dioxide which supported those obtained by Roscoe and Dittmar.

1880. *Naccari and Pagliani*[83] detected an error in the work of Khanikof and Louguinine, and used their results to show agreement with Henry's law. Further work was published[83] later on to the same end.

1884. *Étard*[107] determined the solubility of certain salts in closed tubes at high temperatures, and found the results were practically a continuation of those at ordinary pressures, concluding therefrom that the pressure influence, within the limits of his experiments, was very small.

1885. *Roozeboom*[115] made an extensive investigation of the solubility of hydrogen bromide under pressures varying from 0 to 760 mm., at six different temperatures; when plotted, his results for each temperature form a series of similar curves, which are apparently parabolic.

* In the case of gaseous mixtures *Dalton*[4] discovered that each gas dissolved in accordance with its own partial pressure.

1886. Pressure was regarded by *Alexejeff* [118] as having no special influence on the solubility of a liquid in a liquid.

From a consideration of the influence of pressure in the light of the
1887. theory of mechanical heat, *Braun* [133] supported Sorby's conclusions by adducing mathematical evidence that substances dissolving in their nearly saturated solution with development of heat and diminution of volume have their solubilities increased by pressure; conversely, substances which dissolve either with absorption of heat or with increased volume must be partially precipitated by pressure. Later on in the same year he published [134] experimental verification of his conclusions.

1889. *Woukoloff* [147] published an adverse criticism of the conclusions of Khanikof and Louguinine,* and also of Wroblewski,† that the absorption of carbon dioxide in water does not take place in accordance with Henry's law. It is pointed out that this law only holds when no chemical action occurs; determinations of solubility of this gas in carbon disulphide at various temperatures showed an approximation to Henry's law.

The influence of pressure on the solubility of salts and other sub-
1891. stances was considered at some length by *Van der Waals*,[181] more especially, however, from the mathematical side.

1894. An investigation by *Konowaloff* [225] showed the validity of Henry's law for the dissolution of carbon dioxide in aniline. He also found the dissolution of ammonia in water at about 100° C. only approximated to this law.

V. C.—*Influence of other Substances.*

(i) *Non-electrolytes influenced by Non-electrolytes.*

1889. With oxygen, hydrogen, and carbon monoxide *Lubarsch* [148] found a minimum of absorption occurred in dilute aqueous alcohol at about the same concentration of alcohol as Müller found with carbon dioxide; he suggested that other gases will behave similarly in this respect.

It follows, as a consequence of Nernst's hypothesis to explain the influence of a dissociated substance in solution on the solubility of a second dissolved substance (*vide* Section V. C (iii)), that the presence of a non-ionised substance in the liquid should not influence the solubility of an ionised substance, provided such non-ionised substance is not identical with an ion of that which is ionised.

1891. *Guido Bodländer* [176] subjected this to the test, and, so as to be free from dissociation phenomena, he considered the case of the solubility of sugar as influenced by alcohol.

Using Schiebler's solubility values he found that in aqueous alcohol solutions less sugar is dissolved than in the corresponding quantity of water by itself. This difference increased with increased concentration of alcohol. The expression $\frac{W}{\sqrt[3]{S}} = \text{const.}$ was arrived at as giving the

* *Ann. Ch. Ph.* (4), 11, 412. † *Wied. Ann.*, 8, 29.

solubility of sugar in dilute aqueous alcohol. (W=grms. water; S=grms. subst. dissolved.)

The solubility of various substances, mostly organic compounds, such as *p*-acettoluidide, *a* acetnaphthalide, phenylurea, &c., in aqueous
1894. alcohol at 25° C., was determined by *Antusch*.[223] When the results were expressed as solubility graphs very complicated relationships were found which did not admit of any generalisation.

Holleman and Antusch[226] found that when water is added to alcoholic solutions of such non-electrolytes as benzoylphenylhydrazine, acetanilide, benzamide, &c., the solubility of these substances increases to a maximum, then decreases (*vide* Section VIII.)

V. C.—*Influence of other Substances.*

(ii) *Non-electrolytes influenced by Electrolytes, and Electrolytes influenced by Non-electrolytes.*

1807. *Dalton*[4] established the fact that a liquid absorbed each constituent of a gaseous mixture as if the others were not present, thus obeying the law of summation previously found by him (*vide* Section III. A.)

Probably owing to its bearing upon physiological questions, the absorption of gases by aqueous salt solutions formed the subject of inquiry at a very early date, and will account for the fact that the gas chiefly studied was carbon dioxide. One of the earliest recorded studies
1840. was by *Pagenstechen*,[9] showing that a solution of sodium phosphate absorbed more carbon dioxide than did water alone. This
1846. inquiry was carried further by *Marchand*,[14] and also by *Liebig*,[15]
1851. who concluded that only a part of the gas dissolved as in water,
1857. the remainder interacting chemically with the salt. Similar conclusions to these were arrived at by *L. Meyer*,[26] and in the
1858. following year by *Fernet**.[28]

1861. *Schiff*[32] made a general investigation of the solubility of salts in aqueous alcohol, but could trace no relationship between the decreased solubility and the amount of alcohol added. This problem
1865. was attacked later by *Gerardin*[39] with but little better success, although he ascertained that the character of the solubility-temperature graph was the same for aqueous alcohol as for water. Working with calcium oxide and barium oxide, and ascertaining the solubility of these substances in aqueous solutions of carbon dioxide,
1872. *Schloessing*[51] formulated the law that the values of the tension of carbon dioxide and the weight of bicarbonate in solution form two geometrical progressions of different roots.

1874. Caustic soda and caustic potash were found by *Raoult*[53] materially to decrease the solubility of ammonia in water; also, that ammonium chloride exerted a similar but smaller influence, while the presence of calcium nitrate caused a considerable increase of solubility. In all these cases the effect produced was proportional to the quantity of salt present in solution.

* This work was continued also by *Heidenhain and L. Meyer* (1863).[34]

1875. *Setschenoff*[61] carried out a similar research, as did also
1877. *Mackenzie*[66]; the former, however, went more deeply into the nature of the phenomena, recognising a rather marked difference in the behaviour of various salts; those which exerted chemical action on the gas, and those which did not.

1876. From his own results *Setschenoff*[65] concluded that the absorption coefficient of carbon dioxide in pure sulphuric acid was identical with that in water; the addition of water caused a rapid decrease of this value to a minimum. These results he explained by assuming the absorption of carbon dioxide and the hydration of the acid to proceed equally.

1877. In the following year *Draper*[67] observed the non-electrolyte ether was more soluble in aqueous solutions of hydrogen chloride than in pure water.

1882. *Klepl*[89] found that chemically pure, dry methylic alcohol dissolves anhydrous copper sulphate assuming a bluish-green colour, the addition of a small quantity of water to this solution caused the discharge of the colour and complete precipitation of the copper sulphate as the blue hydrated salt.

1885. Ammonia was found by *Giraud*[116] to be a very effective precipitant of certain salts, notably potassium sulphate, which is thrown out of solution almost completely when the solution contains
1886. about 30 per cent. NH_3. *Setschenoff*[120] continued his work on the absorption of gases in salt solutions, but the results he obtained, like those of *Raoult* (1874), were difficult to interpret because
1887. often the gases used had some chemical action on the dissolved salt.[125] *Müller*[145] investigated the absorption of carbon dioxide
1889. in aqueous alcoholic solutions and found a minimum of absorption at certain concentrations of alcohol; in this, and in other respects, his results were somewhat analogous with those previously recorded by *Setschenoff*.[65]

From a study of the absorption of carbon dioxide in salt solutions *Setschenoff*[142] showed that the absorption coefficient of salt solutions is smaller than that of water, and follows Dalton's law. He also came to the conclusion that a salt solution is a very weak chemical compound of salt and water.

Nernst[144] published an important theoretical discussion of solubility viewing this process as strictly analogous to vaporisation; he arrived at the conclusion that the presence in solution of a non-electrolyte does not affect the solubility of another substance in that liquid.

Evidence running counter to this conclusion of Nernst was published
1891. by *Bodländer*,[176] who found the solubility of potassium chloride, sodium nitrate, and potassium nitrate was affected by the presence of alcohol; the relationship $\frac{W}{\sqrt[3]{S}} = k$ found for sugar and alcohol (*vide* Section V. C (i) 1891) was found to hold with fair approximation.

1892. *Wegner*,[197] and a little later also *Roelofsen*,[213] ascertained
1894. the influence of various concentrations of alcohol on the solubility of potassium hydrogen tartrate.

Steiner[219] determined the absorption coefficient of hydrogen in water

and in aqueous solutions of cane sugar and a number of salts at various concentrations. When his results were compared he was unable to discern any relationship between the various substances examined. Cane sugar appeared particularly active in diminishing the solubility of hydrogen in water.

The general results are contrary to the requirements of Nernst's theory, because the molecular lowering of the solubility coefficient is greatest for dilute solutions.

The solubility of ozone in acidulated water was found by *l'Abbé Mailfert* [227] to be the same as in pure water up to 20° C.; above this temperature it becomes greater than in pure water.

1895. *Goldschmidt* [236] discussed the question of the increase in the solubility of a hydrated salt on the addition of a non-electrolyte. He deduced theoretically an expression for this increase, and found it to be independent of the nature of the non-electrolyte. When tested experimentally with sodium *p*-nitrophenoxide in pure water and in equimolecular solutions of carbamide, glycerol, acetone, and several other substances, each was found to bring about an equal molecular increase of solubility.*

Further results of solubility determinations of gases in aqueous salt solutions were furnished by *Gordon*.[239] In this work nitrous oxide and solutions of the chlorides and sulphates of the alkali and alkaline earth metals were employed. The results obtained by this worker, together with those recorded by Steiner, were used by Jahn in arriving at an empirical law connecting the solubility of a gas and the concentration of salt in solution in the solvent (*vide* Section VIII.).

V. C.—*Influence of other Substances.*

(iii) *Electrolytes influenced by Electrolytes.*

Kopp [10] was probably the first to institute systematic experiments on
1840. the influence of one salt on the solubility of another where no mutual action took place. He found a salt decreased the solubility of a second salt. This subject was more fully investigated by
1841. *Karsten*,[11] who distinguished three cases in the behaviour of saturated salt solutions towards other salts.

1856. *Pfaff* [24] studied the influence on one salt of the solubility of another in water—copper sulphate and sodium sulphate, magnesium sulphate, and sodium sulphate—and could detect no relationship between the solubility of a salt in water and the amount of it that dissolves in water containing another salt in solution. The line of work
1866. taken up by Kopp and by Karsten was continued by *Hauer*,[41]
1868. who showed, more especially in a later publication,[44] that if one salt is added in sufficient excess to a solution of another salt, it is sometimes able wholly to displace the other from solution, provided the salts are isomorphous.

* This work was continued by *Löwenherz*,[241] who examined the influence exerted by carbamide on the solubility of hydrated sodium sulphate.

1873. In an extensive and general study of salt mixtures *Rüdorff*[52] examined the solubility of mixtures of salts, and found that not only isomorphous salts, as Hauer supposed, but also those which form double compounds, expel one another from solution.

The salt mixtures employed were classified as

(i) Where no chemical action could occur—*i.e.*, salts having like acids or bases.

(ii) Where chemical action may take place—*i.e.*, salts of different acids and bases.

1877. *Droezer*[68] found the solubility of gypsum was considerably influenced by the presence in solution of certain salts, while in
1878. the next year *Eder*[71] published results showing that alkaline sulphates do not affect the solubility of silver sulphate in water.

The influence of a salt on the solubility of another salt of similar character—namely, sodium chloride and potassium chloride—formed the
1879. subject of an inquiry by *Schönach.*[77] He found, when water was saturated with both of these salts, the solubility of each became diminished, that of potassium chloride more than sodium chloride; the solubility of the mixture not corresponding with the sum of the solubilities of the two salts. This difference increases with rise of temperature,* the less soluble salt being removed by the more soluble salt in accordance with the law of Hauer.

A knowledge of change in the solubility of so-called sparingly soluble substances owing to the presence of other substances in solution
1881. became of great importance for gravimetric analysis. This appears to have prompted *Ruyssen and Varenne*[84] to investigate the case of several very sparingly soluble compounds. They found, for example, the solubility of silver chloride increases with the concentration of silver nitrate, and also with the concentration of hydrogen chloride, but no well-marked regularities were observed. *Precht and Wittjen*[85] determined the solubility of mixtures of salts of the alkali and alkaline earth metals. The more striking of the results recorded being that when a mixture of potassium sulphate and potassium chloride is treated with water the solubility of the potassium chloride remains practically the same as in pure water; and the solubility of barium chloride when in the presence of sodium chloride does not change with change of temperature.

A discussion of the solubility of metallic chlorides was published by *Ditte*,[86] who classified these salts according as their solubility was (i) increased, or (ii) decreased in the presence of hydrogen chloride. Those which showed an increased solubility he subdivided into the groups (i *a*) those soluble in water, and (i *b*) those insoluble; while the salts which became less soluble were classed as (ii *a*) separating in a less hydrated state, and (ii *b*) in an anhydrous state.

Nicol[102] recounts some experiments regarding the saturation
1884. of a liquid by two salts dissolved simultaneously, which appear to indicate that each salt dissolves independently of the other, and each salt increases the solubility of the other. This increased solubility is not considered as being brought about by any tendency to

* *Vide* footnote, Section V. A (i) 1879.

form homogeneous combinations, but rather by a mechanical interposition of the molecules of the two salts with those of the water.

1885. *Rüdorff*[117] published further results of work on the lines of that previously recorded (1873), and concluded that those salts which are isomorphous or which form together double salts, displace one another from their solutions, while those salts which do not crystallise together do not displace each other from solution. In the following year

1886. there appeared the first of a series of publications by *Engel*,[121] dealing with the somewhat complex case of the solubility of cupric sulphate in presence of ammonium sulphate. This was soon followed by an account[121] of experiments on the precipitation of barium, sodium, ammonium, and strontium chlorides by hydrogen chloride. The conclusion drawn being that the solubility of chlorides which are precipitated from their aqueous solutions by hydrogen chloride became diminished in presence of the acid by the amount which corresponds to one equivalent of chlorine for each equivalent of hydrogen chloride; thus the number of equivalents remaining in solution keeps practically constant. In all cases, except with ammonium chloride where the sum of the equivalents slightly but continuously increases, the sum of the equivalents was found to be diminished somewhat at first and then increased. This law of equivalent precipitation was only found to hold good up to the point where the solubility of the chloride had become reduced to about $\frac{1}{2}$ of its solubility in water. These conclusions of Engel were adversely criticised by *Jeannel*[122] who enunciated the law that the solubility of chlorides in water in the presence of hydrogen chloride varies in such a manner that the sum of the equivalents of salt, acid, and water in the solution remains practically constant at the same temperature, irrespective of the nature of the chlorides.

1887. To this *Engel*[126] replied by publishing results of precipitating magnesium chloride by hydrogen chloride which supported his previous conclusions, although he found some deviation from his equivalent precipitation law with higher concentration of HCl, and also when barium chloride or strontium chloride were the salts employed. This third paper on the effect of hydrogen chloride on the solubility of chlorides dealt with cases of various anhydrous and hydrated salts, and contained results quite in harmony with his law of equivalent precipitation. Similar results were obtained with nitric acid and nitrates. A further publication[126] recorded the behaviour of sulphuric acid as a precipitant for sulphates. In this case, however, the acid behaved as though one equivalent withdrew, or prevented twelve equivalents of water from exerting any solvent action, and the corresponding quantity of salt was precipitated. As with hydrogen chloride this did not hold with strong acid solutions.

1888. In the next year *Engel*[139] published a series of three memoirs treating of the solubility of salts in presence of acids, bases, and salts. The *first*[139] being a general review of the subject; the *second*[139] relating to the solubility of carbonates as influenced by carbonic acid, and also that of oxalates influenced by oxalic acid; the conclusion arrived at being that the law of Schloesing[51] (Section V.

C (ii)) is applicable also to magnesium carbonate, but only in a limited number of cases to the action of dibasic acids on the solubility of their neutral salts. The *third* [139] treated in an extended form of the question of the equivalent precipitation of various chlorides by hydrogen chloride and is a *résumé* of previous publications in the 'Compt. rend.'

1889. A further paper [149] by the same author contained an interesting brief historical review of the subject under investigation, and the collected results of an extensive study of the influence of hydrogen chloride on the solubility of many metallic chlorides—namely, those of tin, copper, cobalt, potassium, lead, mercury, and platinum.

Graphs representing solubility of potassium chloride in water at various temperatures, alone and in presence of sodium chloride, were found by *Étard* [151] to converge towards a temperature of 913°, and the composition of the mixture at the 'limit of solubility temperature'*—738° C.—was calculated [152] to be 16·7 per cent. NaCl and 83·3 per cent. KCl. These weights contain approximately equal quantities of metal (K and Na) and non-metal (Cl).

1889. *Nernst* [144] contributed an important theoretical discussion of the results obtained by Engel and the general nature of the influence exerted by one soluble substance upon another in solution, the explanation offered being strictly comparable with the gas laws and the observations of Horstmann† on dissociated vapours. The conclusions he arrived at were supported qualitatively by the precipitation of potassium chlorate from its saturated solution by potassium chloride and by sodium chlorate, and approximately quantitatively by results of determining the solubility of silver acetate as influenced by sodium acetate and by silver nitrate. He was the first to advance the theory that at a given temperature the solubility of a sparingly soluble electrolyte in water or in aqueous solutions of other electrolytes, is dependent upon a constant which he called the 'solubility product.'

The study of mutual salt influence carried out by Rüdorff was extended by *Meyerhoffer* [157] to conditions where double salt formation takes place. This author examined the change of solubility at the transformation temperature of double salt, and came to the conclusion that each individual substance has a definite solubility temperature-curve, and at the point of the intersection of such curves the composition of each saturated solution must be identical for each curve.

1890. *Noyes* [164] examined the application of Nernst's formula for calculating the solubility of mixed salts, and in some cases with dilute solutions; the results he found were in approximate agreement with the values obtained experimentally. So strong was this author's faith in the above-mentioned hypothesis that he concluded the discrepancy between his calculated values and his experimentally determined values for the solubility was due to the degree of dissociation not being accurately determined by conductivity measurements. He proceeded to calculate the dissociation constant (K) for thallium nitrate from his solubility results, and found a smaller and a fairly constant value. This

* The temperature at which the proportion of water has become reduced to zero, owing to the increased quantity of salt.

† *Ber.*, 1881, 14, 1242.

application by Nernst of the law of 'Mass action' was further discussed by *Le Blanc and Noyes*,[165] who cited several examples of apparent anomalous behaviour; as, for example, mercuric chloride and hydrogen chloride, sodium chloride and potassium chloride, and potassium nitrate and lead nitrate, while sodium nitrate behaves in a normal manner. In these and in other cases of increased solubility, from freezing-point measurements of combination between the two instead of the anticipated decrease, they were able to obtain evidence added electrolytes. In further support of Nernst's hypothesis, the conclusion was arrived at that the solubility of a substance in water is not much influenced by the presence in solution in the water of another substance which does not of itself play the part of a solvent.

The complex case of mutual salt influence when double salt formation takes place—potassium sulphate with copper sulphate—was
1891. examined by *Trevor*.[177] Compared with their solubility in pure water, he found the solubility of the more soluble salt was increased, and that of the less soluble salt diminished. This is in agreement with Nernst's hypothesis, as was pointed out by *Noyes*.[164]

A paper entitled 'Neutral Solution,' by *Nicol*,[185] continued the discussion of phenomena due to the mutual influence of two salts on each other's solubility in water*; more particularly of chlorides and nitrates of sodium and potassium in such combinations that the salt pair contained a constituent in common.

The general conclusion come to was that the presence of one salt diminishes the solubility of the other, except in the case of the nitrates, where an increased solubility was found.

The research of *Bodländer* [176A] on the influence exerted by one salt on the solubility of another—potassium chloride precipitated by potassium nitrate—furnished results which were not in agreement with the views held by Nernst. Bodländer found, for instance, in the above case that the same relationship existed between water and dissolved salt—potassium chloride—as was found when alcohol was the added substance and not potassium nitrate.

Roozeboom [183] determined the solubility of mixed crystals of the isomorphous salts, potassium chlorate and thallium chlorate, and expressed views as to the limitations of Nernst's law of the relative lowering of solubility.

Setschenoff [184] examined the data published in connection with Bodländer's work, and found that, provided the concentration of the solution is not great, the solubility of one salt in the solution of another indifferent salt obeyed the law he had observed to hold for the absorption of carbon dioxide in salt solutions.

This line of work was continued by *Blarez*,[169] who employed potassium hydrogen tartrate and studied the influence of varying quantities of potassium chloride on its solubility.

Besides the solubility of this tartrate being a function of the tem-

* Trevor, *Phil. Mag.* (5) 32, 75, pointed out that the problem discussed in this paper had been solved theoretically and confirmed experimentally by Nernst, Noyes, and himself.

perature, it was found to be a function of the quantity of potassium chloride present; the quantity of tartrate precipitated, when this salt is only present in small quantities, being equivalent to the quantity of chloride added. For solutions containing more KCl than potassium hydrogen tartrate, the expression $Qt = 0{\cdot}05 + 0{\cdot}000005\, t^3 / \sqrt{k}$ was found to hold: in which k = potassium in form of chloride, Qt = quantity of salt in 100 parts of solution at t°. This relationship was found to hold also for the bromide, iodide, chlorate, and nitrate.[169] In other words, the effect depends solely on the weight of potassium present, and is independent of the nature of the acid.

Blarez[169] also found that successive additions of small quantities of potassium chloride to a saturated aqueous solution of potassium sulphate precipitated the sulphate, but the sum of the salts in solution continually increased until a reverse action took place.

Similar observations were made by *Engel*[170] on the influence of alkali bases on the solubility of alkali salts. He found that sodium hydroxide added to a saturated solution of sodium chloride or sodium nitrate, or potassium hydroxide added to a saturated solution of potassium bromide, potassium iodide, or potassium nitrate, precipitated the salt originally in solution approximately in agreement with the rule that 1 molecule of salt is precipitated for each molecule of anhydrous oxide—(Na_2O or K_2O)—that is added.

Experiments by *Blarez*[172] on the solubility of potassium chlorate as influenced by potassium hydroxide and other salts indicated that this more sparingly soluble salt behaves in the same manner as the other potassium salts previously studied.

1892. An attempt was made by *Behrend*[192] to ascertain whether the application of the gas laws to solutions, as made by Van't Hoff, was valid for the case where a double compound becomes resolved into its two components when dissolved in a liquid. As affording evidence to this end, the results recorded leave much to be desired.

Meyerhoffer[196] examined the system $CuCl_2,2H_2O,2KCl + KCl$ and criticised the work of *Trevor* [1891] on the solubility of copper sulphate with potassium sulphate.

1893. *Noyes*[203] criticised Arrhenius'* assumption that all binary salts are equally dissociated in solution, and not only did he quote Arrhenius' own figures to show this, but stated that he himself had found the solubility of potassium tartrate to be reduced to a greater extent by KCl than by KNO_3, and still less reduced by $KClO_3$.

Roozeboom's conclusions were criticised by *Fock*,[206] who commented on the lack of data given by this author. He gave his results for the solubility of potassium sulphate in presence of ammonium sulphate; no proportionality being found between the molecular percentage of one constituent—ammonium sulphate—and the molecular percentage of that constituent in the mixed crystal, nor was it regarded as possible that there should be any such proportionality.

An extension of the study of the influence of added salts on the

* *Zeit. physikal. Chem.*, **11**, 391.

solubility of potassium hydrogen tartrate was published by *Noyes and Clement.*[207] Their results may be briefly summarised as follows:
1894. (i) The three potassium halogen salts decrease the solubility of the tartrate to about the same extent; (ii) potassium nitrate in concentrated solutions causes a smaller decrease in the solubility of the tartrate than is occasioned by the potassium halides: potassium chlorate to even a smaller extent than the nitrate; (iii) potassium acetate causes a decided increase; and (iv) potassium sulphate least effect of all other salts; while (v) hydrogen chloride brings about an increase in the solubility of the $KHC_4H_4O_6$.

With the object of gaining information as to the behaviour of isomorphous salt pairs, *Muthmann and Kuntze* [217] studied the solubility of monopotassium phosphate and arsenate; potassium perchlorate and permanganate; and potassium and rubidium permanganates. Although difficult to interpret, the results seem to be in accord with the conclusions of Roozeboom (*vide* this Section, 1891).

Following a *general review* [214] and amplification of his work, *Étard* [215] recorded an attempt made to measure the solubility of the potassium halide triple mixture, KCl+KBr+KI in water. It was found, however, that these salts were not capable of existing simultaneously in solution; the potassium chloride remaining undissolved in the presence of the other two salts.

A further contribution to the study of mixed hydrated crystals was
1895. published by *Stortenbeker.*[238] The molecular percentage of the two constituent salts are made to serve as ordinates and abscissæ, and the solubility curves drawn, when the following three classes of curves are illustrated:—

(1) The solubility isothermals do not cut—an example being the case of ($MgSO_4,7H_2O$; $ZnSO_4,7H_2O$).

(2) The isothermals cut, but have no breaks—an example being ($CuSO_4,5H_2O$; $FeSO_4,5H_2O$).

(3) The isothermals cut, but one of them has a break—an example being $CuSO_4,5H_2O$; $Mn(SO_4),5H_2O$.

Van Laar [242] investigated thermodynamically the formulæ expressing changes of solubility, and obtained theoretically the following results: When there is one '*ion*' common to both substances the solubility becomes lowered, the least soluble undergoing the greatest relative change. Non-electrolytes were found to have no effect on the solubility, neither are they themselves affected in this respect. When there is no '*ion*' in common, the effects produced are more complex and frequently indeterminable.

VI. *Mutual Solubility and Distribution Coefficients.*

The first to examine the distribution of a substance between two
1872. non-miscible solvents were *Berthelot and Jungfleisch.*[49] Experimenting with iodine and bromine in mixtures of water and carbon bisulphide, also various organic and inorganic acids, and ammonia in mixtures of water and ether, they tried to find some relationship between the partition of the substance and its solubility in

the two solvents. Although unsuccessful in this direction they ascertained that when a substance is simultaneously in the presence of two solvents, the quantities dissolved by equal volumes of each have a constant ratio—coefficient of distribution—which is independent of the relative volumes of the solvents, but varies with the degree of concentration and with the temperature.*

A very thorough investigation of the behaviour of partially miscible
1881. liquids was carried out by *Konowalow*.[87] This work embraced the influence of pressure and temperature on the mutual solubility of water and respectively formic acid, methylic, ethylic, and propylic alcohols.

1884. *Guthrie*[105] studied the solubility relations of partially miscible liquids, as, for example, ethylic alcohol and carbon bisulphide, alkylamines and water, &c.

Having previously shown that the mutual solubility of substances
1886. is not always increased by rise of temperature,† *Alexejeff*[118] came to the conclusion that mutual solubility phenomena are not as simple as the hypothesis of Dossios supposes (*vide* Section VIII., 1867). From numerous experiments it was concluded that liquids which dissolve one another appreciably at ordinary temperatures mix completely at temperatures considerably below their absolute boiling-points, there being no essential difference between the laws of mutual solubility of liquids and solids. This conclusion was experimentally confirmed.

1890. *Nernst*[162] extended the application of the law of distribution of a substance between two solvents, showing that this was dependent upon the substance having the same molecular weight in both solvents. He suggested this as a useful method of ascertaining molecular weights of compounds.

1891. A publication by *Riecke*[174] on the thermal potential for dilute solutions contains results which are in agreement with experimental data for the distribution of a substance between two solvents, and also for the diminution of solubility of a substance by the addition of a second substance. These results, which were arrived at mathematically, are based upon the application of Gibb's equation to the case of dilute solutions.

From the observations of Alexejeff on the solubility of aniline in water and water in aniline at various temperatures, *Masson*[178] found experimental evidence in favour of the view that there is complete analogy between the dissolution and the vaporisation of solid substances.

Berthelot's work on the distribution of a substance between two non-miscible solvents was extended in theory by *Aulich*[179] to the case where four substances were present in chemical equilibrium—two salts with like base and different acids, and also the acids of those salts. This author discussed the relationship between the affinity coefficient and the distribution coefficient of this system.

Küster[183A] published an extension of his previous work ‡ on the

* See also IV. B. † *Vide* also *Bull. Soc. Chim.* (2), **42**, 329.
‡ *Zeitschr. f. physik. Chem.* (1890), **5**, 601.

freezing-points of isomorphous mixtures. He found that Van't Hoff's law for the depression of the freezing-point * was not obeyed in these cases, but that the freezing-points lay in the neighbourhood of the point calculated from the freezing-points of the components of the mixture.

It was found by *Nernst* [180] that a substance which gives a different value for its molecular weight in one solvent from that found with another solvent gives an abnormal value for its distribution coefficient between these liquids. This he attributed to the fact that one liquid acted better as a simplifying agent than the other; a conclusion supported by experiments made with benzoic acid in water and in benzene.

During that year *Roozeboom* [182] expressed views regarding the limitations of Nernst's law of the relative lowering of the solubility

1892. and the partition law; such limitations were, however, strongly contested by *Nernst*.[188]

1894. The mutual solubility of salts engaged the attention of *Le Chatelier* [221]; he distinguished three general cases:—

(1) Salts solidify to form isomorphous mixtures of variable composition.

(2) Each salt solidifies separately from the mixture.

(3) The two salts combine and solidify as a compound of definite composition.

Cases of the first kind having been considered by this author as well as by *Küster*[183A], in this paper instances of the second class are recorded.

Küster [208] investigated the distribution of ether between water and caoutchouc, and found evidence for recognising the existence of a considerable proportion of double ether molecules $2[(C_2H_5)O]$ at low temperatures. From experiments † on the distribution of iodine between water and starch [208A], carried out in the same year, he came to similar conclusions regarding iodine.

1895. *Jakowkin* [243] determined the distribution coefficient of iodine and of bromine between water and some other solvent, and found, with some solvents, that Küster's observations were substantiated, while with other solvents this was not the case.

VII. *Theoretical Considerations.*

Up to the time of Lavoisier the phenomenon of dissolution was regarded as the result of some purely mechanical process, and, to this end, many ingenious explanations were advanced.‡ According to *Lavoisier*, and indeed nearly all the chemists of that period,§ the

* *Zeitschr. f. physik. Chem.* (1890), **5**, 322.

† Further references and details may be obtained from 'Der Verteilungssatz,' by W. Herz, Ahren's *Sammlung*, **15** (i) [1909].

‡ Newton imagined there are spaces in the water, in which the salt takes up position; and to explain how it was that water saturated with one salt was still capable of dissolving another salt, *Gassendi* (Chaptal, *Elements de Chemie*, i. 40; Montpellier, 1790) supposed these spaces to be of different shapes.

§ Berthollet, *Statique Chimique*, p. 50; also Fourcroy, *Système des Connaissances Chimiques*, ii., p. 360.

existence was recognised of a chemical attraction between the molecules of solute and the molecules of solvent.

1839. *Gay-Lussac* held the opinion that dissolution was a physical process,* being dependent upon the molecular state, and showing a great resemblance to the phenomena of fusion and vaporisation.

1840. The researches of *Karston*[11] upon the influence of one salt on the solubility of another, as, for example, the influence of other soluble nitrates on the solubility of sodium nitrate, did not indicate the existence of any law governing the change of solubility; however, it was concluded that aqueous solutions of salts must be regarded as chemical compounds.

1856. These conclusions were further emphasised by *Pfaff*.[24] Some
1866. years later *Mulder*[40] supported the view that solubility was to be regarded as a chemical process, and published his work upon the saturation of water with two salts. Evidence was found therein indicating the formation of some chemical compound (double salt) in solution, the composition of which varied with the temperature, and also with the quantity of the components present.

1867. *Dossios*[43] advanced a theory to explain the difference in solubility of substances, which was based upon the conception of an attraction between the particles of solvent and the particles of solute being greater than the attraction between the solute particles themselves. Unfortunately, no experimental justification for this assumption was given.
1872. *Handl*[50] expressed the opinion that the solubility of a substance is not conditioned by any property of the solvent, but by the establishment of a state of equilibrium between the number of particles leaving the solid body and the number returning. Further work bearing on the nature or theory of solubility was
1875. published by *Pfaundler*,[56] who studied the phenomenon of a crystal changing shape and not weight when kept in its saturated solution; the explanation put forward being that the energy of vibration was unequal on different crystal surfaces. These views were, however, adversely criticised by *Lecoq de Boisbaudran*.[60]

1876. In the following year *Isidor Walz*[64] published 'a contribution to the theory of solubility' in which he adopted an extended view of solution, embracing the molecular intermixture of solids. The size of the molecules and the intermolecular spaces were regarded as having an important bearing upon the solubility of substances.

From an entirely different source—namely, the study of suspension
1878. of clay in water and in saline solutions, *Durham*[70] came to the conclusion that chemical combination, solution, and suspension are all manifestations of the same force, differing only in degree.

1880. *Hannay and Hogarth*[80] observed the solubility of solids in gases, and from their results concluded that the dissolution of a solid substance was a function of all fluids; the requisite condition being molecular closeness and thermal activity.

The behaviour of anhydrous copper sulphate towards anhydrous

* Further observations by this author relative to 'solubility' will be found, *Ann. Ch. Ph.*, 1819 (2), **11**, 296; *ibid.*, 1832 (2), **49**, 393; *ibid.*, 1839 (2), **70**, 423; *Compt. rend.*, 1839, **8**, 1000; and *Ann. Ch. Ph.*, 1845 (3), **13**, 567.

methylic alcohol and towards moist methylic alcohol, observed by
1882. *Klepl*,[89] also the observations of *Goodwin*[93] (*vide* Section V. A),
all point to solubility being dependent upon more than some purely mechanical process; the latter author concluding it to be more of a chemical process at low temperature, and more mechanical at high temperature.

1883. In the next year *Nicol*[96] put forward views on the nature of solution, which had much in common with those previously expressed by Dossios (1867). He suggested a possible relationship exists between molecular volume and solubility of solids, similar to that
1884. found between the molecular volume and the boiling-point of liquids; instances of this were adduced in *a later publication*.[102]

From a very extensive examination of the behaviour of solutions of
1884. a large number of isomeric organic compounds *Traube*[104] was able to conclude that the solubility of a substance and the cohesion of the solution are in some manner directly related.

As a result of further research Nicol[124] showed the solubility
1886. of a salt to be dependent on the relation between the cohesion of the salt and the adhesion of solvent to the salt. *Alexejeff*[118] found the state of aggregation had a decided influence on the solubility of salicylic and of benzoic acids.

The research of *F. Braun*[133] (*vide* Section V. B.) has also
1887. to be mentioned in this section; likewise the relationship, although somewhat obscure, observed by *Kosman*[135] between the amount of salt that saturates 100 parts of water and the molecular weight of the hydrated salt.

A systematic study of the precipitation of salts from their aqueous
1888. solutions by the addition of the corresponding acids led *Engel*[139] to conclude this process to be in no wise due to a dehydrating effect of the added precipitant; in arriving at this conclusion, however, this author entirely neglects to consider any affinity existing between salt and water.

That salt solutions are very weak chemical compounds was
1889. inferred by *Setschenoff*,[142] while almost at the same time *Nernst*[144] regarded the process of dissolution as being perfectly similar to that of vaporisation; the molecules in both cases assuming the gaseous state. The specific attraction between salt and solvent was considered by this investigator to be non-existent; the process of dissolution being independent of such influences. As the distribution of a vapour takes place in the atmosphere of an indifferent gas as in a vacuum, so the solubility was assumed to be unaffected by the presence in solution of a second substance, provided always the two are without chemical action one on the other. The work of Horstmann referred to (*vide* Section V. C (iii, 1889) showed the addition of a product of dissociation caused a separation of the substance vaporised, an indifferent gas not being capable of this action. On these lines the precipitation of a dissociated substance in solution by the addition of a compound giving an 'ion' in common with one in solution was considered as being caused by the increased osmotic partial pressure of that 'ion' being greater than the solubility tension of the solid substance, and

consequently the excess of those 'ions' separate from solution in union with the requisite number of oppositely charged 'ions.' He also introduced the conception of a 'solubility product' (*vide* Section V. C (iii), (1889).

1891. A communication by *Riecke*[174] on the thermal potential for dilute solutions furnished results which are in agreement with experimental data for the distribution of a substance between two solvents and also for the diminution of solubility of a substance when a second substance is added. These results were arrived at mathematically from an application of Gibb's equation to dilute solutions.

Masson[175] discussed the analogy between the dissolution of a solid and the vaporisation of a volatile substance; he mentioned, among other points, that, when regarding these phenomena as related, it becomes necessary that there should be some relationship between the true melting-point of salts and the rates of increased solubility with the temperature; further,[178] substances should exhibit an infinite solubility. The former having been generally established by Tilden and Shenstone, the latter, only in the case of liquids, by Alexejeff.

In an important communication entitled 'The Solubility of Mixed Crystals, more especially of two Isomorphous Substances,' *Roozeboom*[182] considered the question of solubility with the object of throwing light on the analogy between solid and liquid solutions. He adversely criticised Duhem's explanation of the behaviour of isomorphous salt pairs based on Gibb's Phase Rule, and from measurements of the solubility of the mixed crystals of the isomorphous salts, potassium chlorate and thallium chlorate, he expressed views[183] as to the limitations of Nernst's law of the relative lowering of solubility.

1892. These limitations were not acceptable to *Nernst*,[188] as is seen from his communication entitled 'The Solubility of Mixed Crystals.'

Pickering[189] published evidence to show that a substance in solution was in a condition different from that of a gas (*vide* Section V. A (ii)).

The change in the internal friction of the solvent was considered by *Winkler*[190] to be the real cause of the decrease in the absorption power of liquids for gases as the temperature was raised.

Étard[186] concluded from his work on the solubility of mercuric chloride and cupric chloride in various organic solvents, that union takes place between salt and solvent. In some cases, for example, with cupric chloride and methylic alcohol, he was able to isolate the complex that is formed.

Some interesting results were published by *Noyes*[195] which revealed considerable imperfections in the 'ionic' conception as advanced by *Nernst*.[144] The assumption was made that thallous chloride is dissociated to the same degree as the chlorides of the alkali metals at the same concentration, and the dissociation of potassium chloride was calculated from solubility measurements. The results thus obtained differed greatly from the values found from measurements of conductivity.

Étard[200] investigated the solubility of hydrocarbons in organic liquids at low temperatures, and was led to regard the melting-point of the solute as the superior limit of solubility and the melting-point of the

solvent as the inferior limit: all intermediate points as loci of the melting-points of mixtures of solvent and solute.

That union, or interaction, does take place between solvent and solute seems also to follow from the work of *Lobry de Bruyn*.[199] This author found certain hydrated sulphates of dyad metals were soluble to a considerable extent in methylic alcohol, but the solution obtained was unstable, depositing the salt again on standing: the addition of a few drops of water accelerated the deposition. The salt separating from such a solution generally contained less water than that originally held, and, in some cases, a partial replacement of water by methylic alcohol was found to have taken place.

The view expressed by Noyes (*vide* this Section, 1892), more particularly that the degree of dissociation derived from measurements of solubility is more trustworthy than that obtained from measurements of electrical conductivity, was disputed by *Arrhenius*.[201] This

1893. was based upon his observations that the electrical conductivity of a salt differs greatly when calculated from solubility measurements according as the sparingly soluble salt with which it is present is more or less soluble. The law of mass action upon which the calculation is based was not considered applicable to strongly dissociated electrolytes.

1894. *Noyes and Clement* [207] found the solubility of $KHC_4H_4O_6$—potassium hydrogen tartrate—was variously decreased by the addition of potassium salts of halogen acids and by nitric acid, while potassium acetate and hydrochloric acid caused an increase in the solubility of tartrate. These effects were ascribed to the different degree of ionisation of the added salt.

From measurements of the solubility of mercuric chloride, bromide, and iodide, and of iodine in carbon bisulphide (*vide* Section V. A (i), 1894) *Arctowski*[209] was led to regard solutions as ill-defined molecular compounds of solute and solvent. He supposed that when one substance does not dissolve in another it is because the two substances are incapable of forming such molecular compounds. He took great exception to the view that water as a solvent is an inert substance.[210]

These conclusions were supported by the recorded work of *Linebarger*,[211] wherein it is shown that mercuric chloride and sodium chloride combine together, giving a double salt which is soluble in ethylic acetate, and that the solubility of this complex is first of all decreased by the addition of small quantities of NaCl, and, as the amount of NaCl increases, the solubility of both salts becomes increased.

Holleman and Antusch [226] contributed an extension of Bodländer's work, making use of solid non-electrolytes dissolved in aqueous solutions of ethylic alcohol. Among the substances used may be mentioned *p*-acettoluidide, *a*-acetnaphthalide, and also phenylthiocarbamide: Bodländer's * formula was not found to hold for these cases. On the addition of water to the alcohol the solubility usually underwent a

* To this *Bodländer* [282] replied that in some cases he found from Holleman and Antusch's values that his formula did hold provided the substance was only soluble in water and not in alcohol.

marked increase, a maximum was reached, and then the solubility decreased. These results are regarded as being out of harmony with Nernst's views of the mechanism of solution, and certainly with the view that no attraction exists between solvent and solute.

1895. The interesting observation of *Pictet* [230], that the presence of a volatile solvent renders a non-volatile substance completely volatile, also appears to favour this view of the part played by the solvent.

In consequence of Arrhenius' criticism of the previous work, and the conclusions drawn from applying the law of mass action to the study of saturated solutions, *Noyes and Abbot* [228] proceeded to verify the principle of solubility influence. They employed sparingly soluble salts—the chloride, bromate, and thiocyanate of thallium—and were able to advance proof of the following:—

(i) The quantity of a dissolved undissociated salt with which a solution is saturated remains constant when a second salt is added.

(ii) The product of the quantities of the two 'ions' remains the same.

The study of the influence of salts in solution on the solubility of a gaseous non-electrolyte, carried out by *Jahn* [240] and his pupils, enabled this author to formulate the following law correlating solubility of a gas and the concentration of the salt solution, $\frac{a - a'}{M^{2}/_{3}} = k$: in which a' is the absorption coefficient in salt solution, a the absorption coefficient in water, and M the number of molecules of salt in unit volume of solution.

In *Van Laar's* [242] thermodynamical investigation of the formula representing solubility changes, he considered the effect produced by the molecules of the solvent existing as associated aggregates.

VIII. *Chronological Bibliography.*

No.	Date	Author	Reference	Section
1	1790	Gassendi	'Chaptal, Eléments de Chimie,' i. 40	VII.
2	1802	Dalton	'Gilb. Ann.,' 12, 385	III.A.
3	1803	Henry	'Phil. Trans.,' 45	V.B.
4	1807	Dalton	'Mem. Manch. Phil. Soc.,' 1	V.C. i; V.B.
5	1819	Gay-Lussac	'Ann. Chim. Phys.,' (2), 11, 296	V.A. i; VII.
6	1832	Gay-Lussac	'Ann. Chim. Phys.,' (2), 49, 393	VII.
7	1839	Gay-Lussac	'Ann. Chim. Phys.,' (2), 70, 423	VII.
8		Gay-Lussac	'Compt. rend.,' 8, 1000	VII.
9	1840	Pagenstechen	'Buchner's Report.,' 22, 318	V.C. ii.
10		Kopp	'Ann. Chem. Pharm.,' 34, 260	V.A. i; V.C. iii.
11	1841	Karsten	'Abh. Berl. Akad.,' p. 95	V.C. iii; VII.
12	1843	Poggiale	'Ann. Chim. Phys.,' (3), 8, 463	II.A.; V.A. i.
13	1845	Gay-Lussac	'Ann. Chim. Phys.,' (3), 13, 567	VII.
14	1846	Marchand	'J. prakt. Chem.,' 37, 321	V.C. ii.
15	1851	Liebig	'Ann. Chem. Pharm.,' 79, 112	V.C. ii.
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20		Carius	'Ann. Chem. Pharm.,' 94, 129	II.C.
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21	1856	Kremers	'Ann. Phys. Chem.,' (ii), 97, 1	II.A.; V.A. i.
22		Kremers	'Ann. Phys. Chem.,' (ii), 99, 25	V.A.i.
23		Carius	'Ann. Chem. Pharm.,' 99, 129	II.C.; V.A. i.
24		Pfaff	'Ann. Chem. Pharm.,' 99, 224	V.C. iii; VII.
25		Roscoe	'J. Chem. Soc.,' 8, 14	II.C.
26	1857	L. Meyer	'Ann. Phys. Chem.,' (ii), 102, 299	V.C. ii.
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28	1858	Fernet	'Compt. rend.,' 46, 620	V.C. ii.
29	1859	Roscoe and Dittmar	'Ann. Chem. Pharm.,' 112, 349	II.C.; V.B.
30	1861	Moller	'Ann. Chem. Pharm.,' 117, 386	II.A.; V.B.
31		Sims	'Ann. Chem. Pharm.,' 118, 345	V.A. i.
32		Schiff	'Ann. Chem. Pharm.,' 118, 362	V.C. ii.
33	1863	Sorby	'Proc. Roy. Soc.,' 12, 538	V.B.
34		Heidenhain and Meyer	'Ann. Suppl.,' 2, 157	V.C. ii.
35	1864	Robinet	'Compt. rend.,' 58, 608	II.C.
36		Alluard	'Compt. rend.,' 59, 500	V.A. i.
37		Mulder	'Scheik. Verhandel,' 89	V.A. i.
38	1865	Watts	'Ann. Suppl.,' 3, 227	V.A. i.
39		Gerardin	'Ann. Chim. Phys.,' (4), 5, 129	V.C. ii.
40	1866	Mulder	'Jahresber. Chem.,' 19, 65	VII.
41		v. Hauer	'J. prakt. Chem.,' 98, 137	V.C. iii.
42	1867	Khanikof and Louguinine	'Ann. Chim. Phys.,' (4), 11, 412	II.C.; V.B.
43		Dossios	'Jahresber. Chem.,' 92	VII.
44	1868	v. Hauer	'J. prakt. Chem.,' 103, 114	IV.A.; V.C. iii.
45	1869	Sims	'J. Chem. Soc.,' 14, 1	V.B.
46		Nordenskjöld	'Ann. Phys. Chem.,' (ii), 136, 309	V.A. i.
46A		Setschenoff	'Mém. Ac. St. Pétersb.,' (7), 12, 6	V.A. i.
47	1872	Page and Keightley	'J. Chem. Soc.,' 25, 566	II.A.
48		Oudemans	'Zeitsch. anal. Chem.,' 11, 287	II.A.
49		Berthelot and Jungfleisch	'Ann. Chim. Phys.,' (4), 26, 396	IV.B.; VI.
50		Handl	'Wien. Akad. Anz.,' 125	VII.
51		Schloessing	'Compt. rend.,' 74, 1552; 75, 70	V.C. ii.
52	1873	Rüdorff	'Ann. Phys. Chem.,' (ii), 148, 456	V.C. iii.
53	1874	Raoult	'Ann. Chim. Phys.,' (5), 1, 263	II.C.; V.C. ii.
54	1875	Alexejeff	'Ber.,' 8, 265	V.A. i.
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56		Pfaundler	'Chem. Centrb.,' (iii), 6, 498	IV.A.; VII.
57		V. Meyer	'Ber.,' 8, 998	II.A.
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59		Boisbaudran	'Compt. rend.,' 80, 1007	IV.A.
60		Boisbaudran	'Compt. rend.,' 80, 1450	VII.
61		Setschenoff	'Mém. Ac. St. Petersb.,' (7), 22, 6	V.C. ii.
62		Lajoux	'J. Pharm. Chim.,' (4), 22, 249	II.
63	1876	Andrews	'Phil. Mag.,' (5), 1, 78	III.A.
64		Walz	'Pharm. J.,' (3), 6, 8	VII.
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67		Draper . .	'Chem. News,' 35, 87 . . .	V.C. ii.
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69		Hüfner . .	'Ann. Phys. Chem.,' (iii), 1, 629 .	II.C.
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72		Ost . .	'J. prakt. Chem.,' (2), 17, 228 .	IV.B.
73		Bourgoin .	'Compt. rend.,' 87, 62 . . .	IV.B.
74		Schuncke .	'Inaug. Diss. Tübingen' (*vide* 'Zeit. phys. Chem.,' 14, 331)	II.B.
75	1879	Hannay and Hogarth	'Chem. News,' 41, 103 . . .	III.A.
76		Regnault .	'Mém. Ac. St. Petersb.,' (7), 26, 256	III.A.
77		Schönach .	'Wien. Akad. Ber.,' (2), 80, 525 .	V.C. iii.
78		Wroblewski .	'Ann. Phys. Chem.,' (iii), 8, 29 .	V.B.
79		Koehler. .	'Zeitsch. anal. Chem.,' 18, 239 .	II.
80	1880	Hannay and Hogarth	'Proc. Roy. Soc.,' 30, 178 and 484	II.A. ; III.A. ; VII.
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82		Lenier . .	'Arch. Pharm.,' (3), 17, 212 . .	III.A.
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84	1881	Ruyssen and Varenne	'Compt. rend.,' 92, 1459 . .	V.C. iii.
85		Precht and Wittjen	'Ber.,' 14, 1667	V.A. i ; V.C. iii.
86		Ditte . .	'Ann. Chim. Phys.,' (5), 22, 551 .	V.C. iii.
87		Konowalow .	'Ann. Phys. Chem.,' (iii), 34, 219 .	II.B. ; III.A. ; VI.
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89		Klepl . .	'J. prakt. Chem.,' (2), 25, 526 .	V.C. ii ; VII.
90		Leidie . .	'Compt. rend.,' 95, 87 . . .	IV.A.
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92		Hecht . .	'Ann. Chem. Pharm.,' 213, 73 .	V.A. i.
93		Goodwin .	'Ber.,' 15, 3039	V.A. i; VII.
94		Wroblewski .	'Ann. Phys. Chem.,' (3), 17, 103 .	II.C. ; V.A. i.
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96	1883	Nicol . .	'Phil. Mag.,' (5), 15, 91 . . .	VII.
97		De Coppet .	'Ann. Chim. Phys.,' (5), 30, 411	II.A ; V.A. i.
98		Nicol . .	'Phil. Mag.,' (5), 15, 329 . .	II.A.
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104		Traube . .	'Ber.,' 17, 2304	VII.
105		Guthrie .	'Phil. Mag.,' (5), 18, 22, 495 . .	II.B. ; VI.
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107		Étard . .	'Compt. rend.,' 98, 993, 1276 .	II.A.;V.A.i;V.B.
108		Étard . .	'Compt. rend.,' 98, 1432 . .	V.A. i.
109		Chancel and Parmentier	'Compt. rend.,' 99, 892 ; 100, 773.	V.A. i.
110		Roozeboom .	'Rec. Trav. Chim.,' 3, 85 . .	II.C.
111	1885	Henry . .	'Compt. rend.,' 99, 1157 ; 100, 60	IV.B.

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112	1885	Le Chatelier .	'Compt. rend.,' **100**, 50; 441 .	V.A. i; V.A. ii.
113		Raupenstrauch	'Wien. Sitz. Ber.,' **92**, II., 463 .	IV.B.; V.A. i.
114		Guthrie .	'J. Chem. Soc.,' **47**, 94 . . .	II.A.; V.A. i.
115		Roozeboom .	'Rec. Trav. Chim.,' **4**, 102 . .	V.B.
116		Giraud . .	'Bull. Soc. Chim.,' (2), **43**, 552 .	V.C. ii.
117		Rüdorff. .	'Ann. Phys. Chem.,' (3), **25**, 626 .	V.C. iii.
118	1886	Alexejeff .	'Ann. Phys. Chem.,' (3), **28**, 305 .	II.A.; III.A.; IV.A.; V.A. i; V.B.; V.C.iii; VI.; VII.
119		Miczynski .	'Wien. Sitz. Ber.,' **94**, II. 15. .	IV.B.; V.A. i.
120		Setschenoff .	'Mém. Ac. St. Petersb.,' (7), **34**, 3	V.C. ii.
121		Engel . .	'Compt. rend.,' **102**, 113, 619 .	V.C. iii.
122		Jeannel . .	'Compt. rend.,' **103**, 381 . .	V.C. iii.
123		Alexejeff .	'Bull. Soc. Chim.,' **42**, 329 . .	VI.
124		Nicol . .	'Phil. Mag.,' (5), **21**, 70 . . .	VII.
125	1887	Setschenoff .	'Mém. Ac. St. Petersb.,' (7), **35**, 7	V.C. ii.
126		Engel .	'Compt. rend.' **104**, 433, 506. .	V.C. iii.
127		Chancel and Parmentier	'Compt. rend.,' **104**, 474, 881 .	V.A. ii.
128		Étard . .	'Compt. rend.,' **104**, 1614 . .	V.A. i.
129		Le Chatelier .	'Compt. rend.,' **104**, 679 . .	V.A. ii.
130		Gniewosz and Walfisz	'Zeitschr. physikal. Chem.,' **1**, 70 .	III.B.
131		Schröder .	'J. russ. phys. Chem.,' **19**, 180 .	IV.A.
132		Sedlitzky .	'Monatsh.,' **8**, 563	IV.B.; V.A. i.
133		Braun . .	'Ann. Phys. Chem.,' (3), **30**, 250 .	V.B.; VII.
134		Braun . .	'Zeitschr. physikal. Chem.,' **1**, 259	V.B.
135		Kosman .	'Chem. Zeit.,' **11**, 903 . . .	VII.
136	1888	Carnelley and Thomson .	'J. Chem. Soc.,' **53**, 782 . . .	III.A.; IV.B.
137		Étard . .	'Compt. rend.,' 106, 206, 740 .	V.A. i.
138		Roozeboom .	'Zeitschr. physikal. Chem.,' **2**, 513	V.A. i.
139		Engel . .	'Ann. Chim. Phys.,' (6), **13**, 132, 344, 370	V.C. iii; VII.
140	1889	Roozeboom .	'Rec. Trav. Chim.,' **8**, 1. . .	V.A. i.
141		Roozeboom .	'Rec. Trav. Chim.,' **8**, 257 . .	III.A.; IV.A.
142		Setschenoff .	'Zeitschr. physikal. Chem.,' **4**, 117	V.C. ii; VII.
143		Étard . .	'Compt. rend.,' **108**, 176 . .	II.A.; V.A. i.
144		Nernst . .	'Zeitschr. physikal. Chem.,' **4**, 372	V.C. ii; V.C. iii; VII.
145		Müller . .	'Ann. Phys. Chem.,' (3), **37**, 24 .	V.C. ii.
146		Le Chatelier .	'Compt. rend.,' **108**, 565 . .	V.A. i.
147		Woukoloff .	'Compt. rend.,' **108**, 674 . .	III.B.; V.B.
148		Lubarsch .	'Ann. Phys. Chem.,' (3), **37**, 524 .	V.C. i; II.C.
149		Engel . .	'Ann. Chim. Phys.,' (6), **17**, 338 .	V.C. iii.
150		Woukoloff .	'Compt. rend.,' **109**, 61 . . .	III. B.
151		Étard . .	'Compt. rend.,' **109**, 740 . .	V.A. i; V.A. iii.
152		Étard . .	'Bull. Soc. Chem.,' (3), **2**, 729 .	V.A. i.
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154		Pettersson and Sondén	'Ber.,' **22**, 1439	II.C.; V.A. i.
155		Pagliani	'Gazzetta,' **19**, 235	V.A. ii.
156		Winkler. .	'Ber.,' **22**, 1766	II.C.
157	1890	Meyerhoffer .	'Zeitschr. physikal. Chem.,' **5**, 99	II.A.; V.A. i; V.C. iii.
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162		Nernst . .	'Zeitschr. physikal. Chem.,' 6, 35.	VI.
163		Timofejew ,	'Zeitschr. physikal. Chem.,' 6, 141	II.C. ; V.A. i.
164		Noyes . .	'Zeitschr. physikal. Chem.,' 6, 241	II.A. ; V.C. iii.
165		Le Blanc and Noyes	'Zeitschr. physikal. Chem.,' 6, 385	V.C. iii.
166		Doyer . .	'Zeitschr. physikal. Chem.,' 6, 481	II.B.;II.C.;IV.B.
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170		Engel . .	'Compt. rend.,' 112, 1130 . .	V.C. iii.
171		Timofejew .	'Compt. rend.,' 112, 1137, 1223 .	V.A. ii.
172		Blarez . .	'Compt. rend.,' 112, 1213 . .	V.C. iii.
173		Étard . .	'Compt. rend.,' 113, 699 . .	V.A. i.
174		Riecke . .	'Zeitschr. physikal. Chem.,' 7, 108	VI., VII.
175		Masson . .	'Nature,' 43, 345	VII.
176		Bodländer .	'Zeitschr. physikal. Chem.,' 7, 308	V.C. i ; V.C. ii.
176A		Bodländer .	'Zeitschr. physikal. Chem.,' 7, 358	V.C. iii.
177		Trevor. . .	'Zeitschr. physikal. Chem.,' 7, 468	V.C. iii.
178		Masson . .	'Zeitschr. physikal. Chem.,' 7, 500	VI., VII.
179		Aulich . .	'Zeitschr. physikal. Chem.,' 8, 105	VI.
180		Nernst . .	'Zeistchr. physikal. Chem.,' 8, 110	VI.
181		Van der Waals	'Zeitschr. physikal. Chem.,' 8, 195	V.B.
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183		Roozeboom .	'Zeitschr. physikal. Chem.,' 8, 531	V.C. iii ; VII.
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184		Setschenoff .	'Zeitschr. physikal. Chem.,' 8, 657	V.C. iii.
185		Nicol . .	'Phil. Mag.,' (5), 31, 369 . .	V.C. iii.
186	1892	Etard . .	'Compt. rend.,' 114, 112 . .	III.B. ; V.A. i ; VII.
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189		Pickering .	'Phil. Mag.,' (5), 34, 35 . . .	V.A. ii ; VII.
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192		Behrend .	'Zeitschr. physikal. Chem.,' 9, 405	V.C. iii.
193		Henrich . .	'Zeitschr. physikal. Chem.,' 9, 435	V.A. i.
194		Kurnakoff .	'J. russ. phys. Chem. Soc.,' 24, 629	IV.B.
195		Noyes . .	'Zeitschr. physikal. Chem.,' 9, 603	VII.
196		Meyerhoffer .	'Zeitschr. physikal. Chem.,' 9, 641	V.C. iii.
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198		Roozeboom .	'Zeitschr. physikal. Chem.,' 10, 145	IV.B. ; V.A. i.
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200		Étard . .	'Compt. rend.,' 115, 950. . .	III.A. ; V.A. i ; VII.
201	1893	Arrhenius .	'Zeitschr. physikal. Chem.,' 11, 391	VII.
202		Schröder .	'Zeitschr. physikal. Chem.,' 11, 449	V.A. i.
203		Noyes . .	'Zeitschr. physikal. Chem.,' 12, 162	V.C. iii.
204		Kohlrausch and Rose	'Zeitschr. physikal. Chem.,' 12, 234	II.A.
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209		Arctowski .	'Zeitschr. anorg. Chem.,' 6, 260 .	V.A. i; VII.
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216		Thorp and Rodger	'J. Chem. Soc.,' 65, 782. . .	III.A.; V.A. i.
217		Muthmann and Kuntze .	'Zeitschr. f. Kryst. Min.,' 23, 368	V.c. iii.
218		Schuncke .	'Zeitschr. physikal. Chem.,' 14, 331	V.A. i.
219		Steiner . .	'Ann. Phys. Chem.,' (3), 52, 275 .	III.B.; V.c. ii.
220		Lieben . .	'Monatsh.,' 15, 404 . . .	IV.B.
221		Le Chatelier .	'Compt. rend.,' 118, 638, 709 .	IV.A.; VI.
222		Pickering .	'Ber.,' 27, 67	V.A. ii.
223		Antusch .	'Diss. Groningen'	V.c. i.
224		Van Laar .	'Zeitschr. physikal. Chem.,' 15, 457	V.A. ii.
225		Konowaloff .	'J. russ. phys. Chem. Soc.,' 26, 48	V.B.
226		Holleman and Antusch .	'Rec. Trav. Chim.,' 13, 277 . .	V.c. i; VII.
227		L'Abbé Maillfert	'Compt. rend.,' 119, 951 . .	V.c. ii.
228	1895	Noyes & Abbot	'Zeitschr. physikal. Chem.,' 16, 125	VII.
229		Bancroft .	'Phys. Rev. Cornell.,' 3, 22 . .	II.B.
230		Pictet . .	'Compt. rend.,' 120, 64 . . .	III.A.; VII.
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232		Bodländer .	'Zeitschr. physikal. Chem.,' 16, 729	VII.
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234		Arctowski .	'Compt. rend.,' 121, 123 . .	V.A. i.
235		Vaubel . .	'J. prakt. Chem.,' (2), 52, 72 .	IV.B.
236		Goldschmidt.	'Zeitschr. physikal. Chem.,' 17, 145	V.c. ii.
237		Linebarger .	'Amer. J. Sci.,' 49, 48 . . .	V.A. i.
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240		Jahn . .	'Zeitschr. physikal. Chem.,' 18, 8.	VII.
241		Löwenherz .	'Zeitschr. physikal. Chem.,' 18, 80	V.c. ii.
242		Van Laar .	'Zeitschr. physikal. Chem.,' 18, 245	V.c. iii; VII.
243		Jakowkin .	'Zeitschr. physikal. Chem.,' 18, 585	VI.

Report on Gaseous Combustion.

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[Ordered by the General Committee to be printed *in extenso*.]

[PLATE VII.]

[This Report aims at summarising the results of the principal researches upon the chemical aspects of gaseous combustion during the past thirty years.]

SYNOPSIS.

INTRODUCTION.—The earlier work of Davy and Bunsen. The latter's erroneous assumption of 'discontinuity' in gaseous combustion. The new era inaugurated by the investigations of Mallard and Le Chatelier, Berthelot and Vieille, and of H. B. Dixon and H. B. Baker.

SECTION I. *Ignition Temperatures and the Initial Phases of Gaseous Explosions.*—Slow combustion below the ignition-point. Recent determinations of ignition temperatures by H. B. Dixon and H. F. Coward. Rates of ignition. Photographic researches of Mallard and Le Chatelier and of H. B. Dixon and his pupils upon the initial phases of gaseous explosions and the influence of reflected compression waves in accelerating combustion and determining detonation. Discovery of 'retonation' and its bearing upon the question of residual or continued combustion in gaseous explosions.

SECTION II. *The Explosion Wave.*—Discovery by Berthelot and Vieille of 'detonation' (*l'onde explosive*) in gaseous explosions. Theories advanced by Berthelot, H. B. Dixon, and D. L. Chapman respecting rates of explosion. Influence of inert gases upon rates of explosion. Inferences to be drawn from observed rates of explosion respecting the combustion of gaseous carbon and of hydrocarbons.

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INTRODUCTION.

THE era in the scientific investigation of gaseous combustion with which this Report is specially concerned was inaugurated some thirty years ago by the pioneering researches of the French savants Mallard and Le Chatelier, and M. Berthelot, on the initial stages of 'inflammation' and the setting up of 'detonation' in explosive mixtures, and by the equally fruitful discoveries of H. B. Dixon and H. B. Baker concerning the part played by steam in combustion. Previous knowledge of the chemistry of fire had been mainly derived from the researches of Davy and his contemporaries (1815 to 1825), and those carried out or inspired by Bunsen some fifty years later. Davy's work, primarily undertaken in order to elucidate the causes of explosions in coal-mines, had disclosed and brought within range of experimental inquiry the broad facts connected with the ignition of explosive mixtures, the influence of narrow passages and of cold surfaces in extinguishing flames, the relative 'combustibilities' and 'explosion limits' of inflammable gases, and the effects of rarefaction and dilution upon gaseous combustion. Finally, his notable discovery of the flameless combustion of hydrogen and of coal-gas in contact with a glowing spiral of platinum, followed by the more systematic investigations of Dulong and Thénard, had drawn attention to the 'intensifying' influence of hot surfaces upon combustion, the importance of which has perhaps never been fully appreciated.

But the work of Davy, standing as it does between the ages of Lavoisier and Clausius, and singularly fruitful as it was in its immediate practical results, gave rise to no great theoretical developments. Soon after his death the path of progress became choked with error; there arose the dogma of the selective combustion of hydrogen in hydrocarbon flames, which, although inconsistent with Dalton's experiments on the partial combustion of ethylene and methane, continued to dominate chemical science for more than half a century. There is no evidence that Davy himself ever countenanced this doctrine, but it possibly may have been suggested to his immediate successors by his mistaken views concerning the much higher combustibility of hydrogen as compared with hydrocarbons—a notion which is still widely prevalent.

Bunsen's researches upon gaseous combustion, whilst they did incalculable service to chemistry and metallurgy in introducing exact methods of gas analysis and in elucidating the reducing action of carbon monoxide in the blast furnace, unfortunately gave rise to certain misconceptions, due to unsuspected errors in the experimental methods employed. His experiments on the division of oxygen between carbon monoxide and hydrogen, which were originally undertaken to test the law of mass action, are now recognised to have been vitiated by the fact that he worked with undried gases in a 'wet' eudiometer. From his results, however, he concluded that the condition of equilibrium in such a case is determined by an assumed tendency to form certain 'hydrates of carbon dioxide,' and undergoes discontinuous alteration on gradual change in the relative proportions of the combustible gases originally present. But whilst this conclusion was afterwards disproved by the independent researches of H. B. Dixon and Horstmann, the underlying

notion of 'discontinuity' or variation *per saltum* in regard to gaseous combustion is still occasionally met with in technical literature.

A similar error crept into Bunsen's interpretation of the results of his measurements of the pressures produced when either hydrogen or carbon monoxide is exploded with half its own volume of oxygen at atmospheric pressure in a closed vessel. He contended that, in either case, *one-third* only of the gases combine in the first instance, whereby the temperature of the system is raised to some point between 2844° and 3033°; that it then falls by radiation to 2558°, between which point and 1146° a further *one-sixth* of the mixture combines, leaving the remaining *half* to burn as the system cools down to the ordinary temperature. This idea of combustion *per saltum* was revived again by von Oettingen and von Gernet in 1888, in connection with their photographic researches on the explosion of electrolytic gas,[1] but it has been clearly proved by H. B. Dixon that their observations can be explained on other grounds.

Bunsen's first measurements of the rates at which flames are propagated in gaseous mixtures (namely, 34 metres per second for a mixture $2H_2 + O_2$, and 1 metre per second for a mixture $2CO + O_2$) have since been shown to apply only to the initial stages of an explosion, where the gases combine with relatively very slow velocities compared with those characteristic of 'detonation.' It was in the year 1881 that Berthelot, and independently Mallard and Le Chatelier, announced the discovery of the rapid acceleration of the initial velocity of inflammation and the final attainment of the enormously higher constant velocity of the 'explosion wave.'

SECTION I.—*Ignition Temperatures and the Initial Phases of Gaseous Explosions.*

Chemical change may be determined in a gaseous explosive mixture at a much lower temperature than its ignition point. Thus, if electrolytic gas be heated in a sealed bulb to a temperature somewhat higher than 400°, the formation of steam can usually be detected after a lapse of a few days. Between 450° and 500° the rate of combination, although considerably greater, would still be insufficient to cause any self-heating of the mixture. If, however, the temperature of the enclosure be further slowly raised, a point (probably about 550°) would soon be reached at which self-heating of the mixture would begin; its temperature would thus be raised above that of the enclosure, and the rate of combination rapidly accelerated until explosive combustion would be set up. The precise temperature at which this would occur would obviously depend upon the amount of slow combustion which had taken place during the preliminary heating-up of the mixture. Thus it follows that the only way of determining the true ignition temperature of such a mixture, undiluted by the products of its own slow combustion, would be either to make the preliminary heating-up period negligibly short, or, better still, to heat separately the combustible gas and the air or oxygen to the ignition temperature before allowing them to mix.

The work of Victor Meyer and his pupils,[2] as also that of Hélier[3]

[1] *Annalen der Phys. und Chemie*, **33**, 586.

[2] *Ber.*, 1892, **25**, 622; 1893, **26**, 2421; *Zeit. Phys. Chem.*, 1893, **2**, 28.

[3] *Ann. Chim. Phys.*, 1897 [vii.], **10**, 521.

and Emich,[1] which yielded very discordant results for the ignition temperatures of mixtures of the commoner inflammable gases with oxygen, doubtless suffered from the large amount of flameless combustion which occurred before the temperature of the mixture as a whole had been raised to the true ignition-point.

Quite recently, however, H. B. Dixon and H. F. Coward,[2] using an apparatus in which the combustible gas and air or oxygen were separately heated to the temperature of the enclosure before being allowed to mix, have succeeded in fixing, within narrow limits, the ignition temperatures at atmospheric pressure of a number of gases. In the cases of hydrogen, carbon monoxide, and acetylene, the ignition temperatures were practically the same in air as in oxygen, thus:—

	In Air	In Oxygen
Hydrogen	580°–590°	580°–590°
Carbon monoxide (moist) .	644°–658°	637°–658°
Acetylene	406°–440°	416°–440°

In most other cases, however, the limiting temperatures observed in air were higher than in oxygen, thus:—

	In Air	In Oxygen
Methane	650°–750°	556°–700°
Ethylene	542°–547°	500°–519°
Cyanogen	850°–862°	803°–818°

Another notable fact is that in an homologous series of hydrocarbons the limiting ignition temperatures appear to fall as the series is ascended. Thus we have (in oxygen):—

Methane, 556° — 700°; Ethane, 520° — 630°; Propane, 490° — 570°.

During 1906-07 K. G. Falk,[3] acting on a suggestion by Nernst, endeavoured to determine the ignition points of various mixtures of hydrogen and oxygen by compressing them in a steel cylinder by means of a weight falling on a piston. Assuming that (1) the mixture was heated adiabatically and uniformly throughout its whole mass until it reached the ignition point, (2) that the whole then detonated instantaneously, and (3) that the downward movement of the piston was arrested at the moment of ignition, he calculated the ignition temperatures under adiabatic compression shown in the table given below.

H. B. Dixon,[4] in a recent criticism of Falk's assumptions, contends that whilst (1) may be in certain cases practically true, (2) and (3) cannot be allowed, and also that Falk's results are unreliable on account of his having neglected to stop the descent of the piston the moment the gases were brought to the true ignition point. Adopting this necessary precaution, Dixon has repeated Falk's experiments, with results which compare as follows when γ is assumed to be 1·40 in all cases:—

[1] *Monatsch.*, 1900, **21**, 1061.
[2] *Trans. Chem. Soc.*, 1909, **95**, 514.
[3] *Journ. Amer. Chem. Soc.*, **28**, 1517; **29**, 1536.
[4] *Trans. Chem. Soc.*, 1910, **97**, 674.

Mixture	Ignition Temperature under Adiabatic Compression: Falk	Dixon
$4H_2+O_2$	605°	—
$2H_2+O_2$	540°	536°
H_2+O_2	514°	530°
H_2+2O_2	530°	520°
H_2+4O_2	571°	507°

Using the specific heats of hydrogen and air found by Joly under high pressures, Dixon calculates the ignition-point of electrolytic gas to be 557° from his experiments on adiabatic compression. From Dixon's results it would also appear that successive additions of oxygen to electrolytic gas regularly lower the ignition-point.

We are principally indebted to the photographic researches of H. B. Dixon and his pupils [1] for the most notable recent additions to our knowledge concerning the initial phases of explosion and the phenomena associated with the setting up of 'detonation' in gaseous mixtures. The first investigators to use a photographic method were Mallard and Le Chatelier in their researches on the initial phases of gaseous explosions.[2] They recorded the movement of the flame along a horizontal glass tube on a sensitised plate moving vertically, thus obtaining a graph compounded of the two velocities. Failing to obtain any satisfactory records with such feebly luminous flames as those yielded by mixtures either of carbon monoxide or of hydrogen with oxygen, they employed mixtures of carbon disulphide with either oxygen or nitric oxide, which they regarded as typical of all 'oxygen' or 'air' mixtures respectively.

The behaviour of these mixtures was found to differ according as they were ignited near (*a*) the *open* or (*b*) the *closed* end of a tube. In the case of (*a*) the flame proceeded for some distance down the tube at a practically uniform velocity, which is the true rate of propagation 'by conduction'; with the mixture CS_2+6NO this state was succeeded by an oscillatory period, the flame swinging backwards and forwards with increasing amplitudes, and then either dying out altogether or giving rise to 'detonation'; with the oxygen mixtures the initial period of uniform slow velocity was shorter, and appeared to be abruptly succeeded by detonation without the intervention of any oscillatory period. When the nitric oxide mixtures were ignited near the *closed* end of the tube, the forward movement of the flame was uniformly accelerated until detonation was set up.

According to Le Chatelier the following numbers represent in *metres per second* the true initial rates of inflammation (*i.e.*, of the propagation of the flames 'by conduction') for various mixtures:—

Hydrogen and Air.

Hydrogen, per cent.	10	20	30	40	50	60	70
Metres, per sec.	0·60	1·95	3·30	4·37	3·45	2·30	1·10

Methane and Air.

Methane, per cent.	6	8	10	12	14	16
Metres, per sec.	0·03	0·23	0·42	0·61	0·36	0·10

[1] *Phil. Trans.*, 1903, Series A, 200, 315.

[2] *Annales des Mines*, 8e Sér., 4.

Acetylene and Air.

Acetylene, per cent.	2·9	5	7	9	15	22	40	60	64
Metres, per sec.	0·1	2	4	6	3	0·4	0·22	0·07	0·05

Coal Gas and Air.

Gas, per cent.	8	10	12	14	15	17	20	24
Metres, per sec.	0·30	0·50	0·72	0·93	1·05	1·27	0·80	0·40

Oxygen Mixtures.

$2CO + O_2$	2 metres per sec.
$2H_2 + O_2$	20 " "
$CS_2 + 3O_2$	22 " "
$C_2H_2 + 2\frac{1}{2}O_2$	200 " "

It should be noted that for mixtures of the same gas with various proportions of air, the initial rate of inflammation attains a maximum when the combustible gas is present in considerable excess of that required for perfect combustion.

H. B. Dixon's experimental method consisted in photographing the explosion flame travelling along a horizontal tube on a highly sensitive film rotated vertically with a constant high velocity (varying, however, between twenty-five and fifty metres per second in different experiments), the explosion tube being placed at such a distance from the camera that the size of the image was about one-thirtieth that of the flame. In this way it was found possible to analyse the progress of an explosion from its point of origin up to the final attainment of its maximum force and velocity in '*detonation*.' The investigation also included the discovery of the wave of '*retonation*,' which is thrown back through the still burning gases from the point where detonation starts (a phenomenon also independently discovered by Le Chatelier in 1900), of the effects of collision between two explosion waves, and of the passage of reflected waves through the hot products of explosion.

The phenomena associated with the development of an explosion in a gaseous mixture, fired in a closed tube by a spark passed between wires a few inches from the closed end, are very clearly shown in the photograph reproduced in fig. 1 (Plate VII.), which is analysed in the diagram fig. 2 (Plate VII.). This photograph was taken during an experiment in which carbon disulphide was exploded with a quantity of oxygen represented by the expression CS_2+5O_2. The flame, in starting at the point O, sends out invisible compression waves in both directions along the tube, which travel in advance of the flame with the velocity of sound through the unburnt gases, as represented by the dotted lines O M, O N in the diagram. The flame itself, travelling at first more slowly than the compression waves, traces the curves O A and O B. The compression wave O N, on reaching the closed end of the tube, is reflected back again as N C, and, on meeting the flame (which is still travelling in the direction O A), retards it, and passes thence through the hot and probably still burning gases as the visible wave C D. An instant later it overtakes at D the front of the flame, travelling in the direction O B, thereby accelerating it and increasing its luminosity in consequence of the quickened combustion. The flame then continues to move forward with rapidly accelerated velocity until 'detonation' is set up at the point E. At this point a strongly luminous wave of compression E G (the 'retonation wave') is sent backwards through the still burning gases, which, on

FIG. 1.

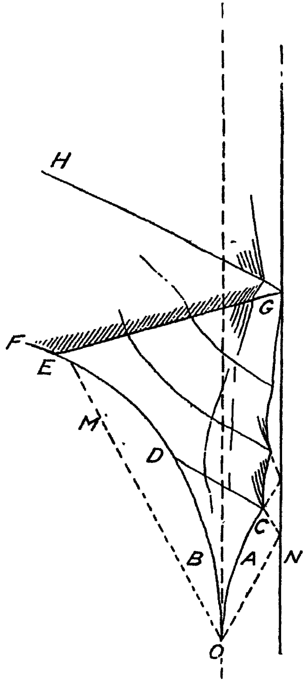

FIG. 2.

FIG. 3.

Illustrating the Report on Gaseous Combustion.

reaching the near end of the tube, is reflected back again as G H. The 'detonation wave' E F passes onwards through the mixture with its characteristic uniform high velocity and intense luminosity. Fig. 3 (Plate VII.) is a similar photograph showing the development of 'detonation' and the phenomenon of 'retonation' in the case of a mixture of cyanogen and oxygen ($C_2N_2+O_2$) fired near the closed end of a tube.

Except in special circumstances (*e.g.*, when it is reinforced by another reflected wave) the velocity of the retonation wave is always inferior to that of detonation; thus Le Chatelier gives 2,990 metres per second for the 'detonation wave' and 2,330 metres per second for the 'retonation wave' in an equimolecular mixture of acetylene and oxygen. When, however, the 'retonation wave' is developed just at the closed end of a tube (*e.g.*, when the explosive mixture is fired at such a distance from the closed end that 'detonation' is set up just as the flame arrives at the end) it may be reinforced by a reflected wave, in which case its velocity cannot be distinguished from that of a true 'detonation.'

The explanation of the intense luminosity of the retonation wave, and its higher velocity than sound through the exploded gases, is to be found in the fact that the combustion during the initial stages of an explosion is very much slower than when detonation is set up. Under the extreme conditions of 'detonation' the temperature of each successive layer of the explosive mixture is suddenly raised to the ignition point by adiabatic compression, and it is probable that a large proportion of collisions between chemically opposite molecules are fruitful of change. The whole combustion is probably completed in an immeasurably short interval of time, as the result of a comparatively limited number of successive molecular collisions. But during the initial period of the explosion ('inflammation') not only is the flame propagated with a much slower velocity, but also the actual process of combustion is much more prolonged than in detonation, and at the moment when detonation is set up combustion is still proceeding in the layers of gas for some distance behind the flame-front. The 'retonation' wave, in passing backwards through these layers, quickens this residual combustion, and is itself thereby rendered highly luminous. This interpretation is supported by the repeated observations of Dixon that the collision of two flames, in neither of which 'detonation' has been determined, will frequently give rise to reflected waves more rapid and more luminous than the incident waves. There can be little doubt as to the important part played by reflected waves in determining the violent shattering effects associated with gaseous explosions on a large scale.

SECTION II.—*The Explosion Wave.*

Berthelot and Vieille, in announcing their discovery of the development of denotation ('l'onde explosive') in gaseous explosions,[1] described it as '*une certaine surface régulaire, où se développe la transformation, et qui réalise un même état de combinaison, de température, de pressure, etc. Cette surface, une fois produite, se propage ensuite, de couche en*

[1] *Ann. Chim. Phys.*, 1881 [5], **28**, 289.

couche, dans la masse tout entière, par suite de la transmission des chocs successifs des molécules gazeuses amenées à un état vibratoire plus intense en raison de la chaleur dégagée dans leur combinaison, et transformées sur place, ou, plus exactement, avec un faible déplacement relatif . . .' Such conditions are comparable with those of a sound wave passing through the gaseous mixture, with, however, the important difference that, whereas a sound wave is propagated from layer to layer with a small compression and a velocity determined solely by the physical condition of the vibrating medium, it is an abrupt change in chemical condition which is propagated in the explosion wave, and which generates an enormous force as it passes through each successive layer of the medium. Berthelot considered that the mean velocity of translation of the molecules of the products of combustion, retaining the total kinetic energy corresponding to the heat developed in the reaction, may be regarded as the limiting maximum rate of propagation of the explosion wave (θ), which would be given in metres per second by the equation.

$$\theta = 29{\cdot}354\sqrt{\frac{T}{\rho}},$$

where T is the absolute temperature and ρ the density of the products referred to air. In calculating T, Berthelot made two erroneous assumptions—namely, (1) that the specific heats of the products are independent of temperature and equal to the sum of the specific heats of the reacting gases, and (2) that the gases burn under conditions of constant pressure. He was also of opinion that, owing to the high pressures generated, dissociation plays no appreciable part in the phenomena of the wave.

In their experimental work Berthelot and Vieille proved that the velocity of the explosion wave is independent of the length of the column of gas traversed, and of the material or diameter of the tube employed (at least above a certain small limiting diameter). It was also immaterial whether the tube was laid out straight, coiled round a drum, or even zigzagged. They also concluded that the velocity is independent of the initial pressure, but this is not strictly correct, as H. B. Dixon has since shown. The rate increases slightly with the initial pressure, attaining a nearly constant value at a pressure of about two atmospheres.

H. B. Dixon, the bearing of whose researches upon the question of the mechanism of combustion will be discussed later, modified Berthelot's theory in the following particulars:[1] namely, by assuming (1) that the explosion wave is carried forward by movements of molecules of density intermediate between that of the products of combustion and that of the unburnt gas; (2) that the gases are heated at constant volume; (3) that the temperature of the gas propagating the wave is double that due to chemical reaction alone; (4) that the temperature is increased when the chemical volume of the products is larger, and diminished when it is smaller, than that of the unburnt gases; and (5) that the velocity of a sound wave is only 0·7 of

[1] The reader is referred to the original memoir in the *Phil. Trans.*, 1893, 184, 97, for the details of the argument.

the mean velocity of the molecules in the gas. Dixon's formula for the rate of explosion of a given mixture is, therefore, as follows:—

$$v=0\cdot7\times29\cdot354\sqrt{\frac{\left(2\frac{Q}{Cv}+T\right)\left(\frac{v_2}{v_1}\right)^{\gamma-1}}{\rho}}$$

where Q = the heat developed by the reaction, v_2 and v_1 = the chemical volumes of the products and unburnt gases respectively, ρ = the mean density of the products and the unburnt gases, and Cv = the specific heat of the products at constant volume, which Dixon wrongly assumed to be independent of the temperature, T = the temperature in C°, and γ = the ratio of the specific heats.

But, whereas the values of v, calculated by this formula, do in many instances correspond with those actually found (*e.g.*, for mixtures of cyanogen and oxygen, and in nearly all cases where the detonating mixture is largely diluted with an inert gas), there are a large number of cases of undiluted detonating mixtures in which the agreement is not good (*e.g.*, for $2H_2+O_2$ the calculated value is 3,416, whereas that actually found is only 2,821 metres per second). Dixon ascribed such discrepancies to the partial dissociation of the products in the wave, but there is now little doubt that the formula does not hold good, as Dixon himself readily enough admits.[1] Nevertheless for many years it was a valuable working hypothesis and inspired much fruitful investigation.

In 1899 D. L. Chapman, following up a suggestion made by Schuster at the time when Dixon's memoir was published,[2] deduced a formula for rates of explosion from Riemann's equation for the propagation of an abrupt variation in the density and pressure of a gas, on the assumption that such a variation can be propagated without change of type.[3] According to this view the explosion wave is to be regarded as a wave of compression not in a homogeneous medium, but in a medium which is discontinuous in the vicinity of the wave-front. It is assumed (1) that the 'front' of the wave (*i.e.*, from the unexploded gas to the point of maximum pressure) does not alter in character, or, in other words, that every portion of the wave travels with the same velocity; (2) that the velocity is the minimum velocity consistent with (1); and (3) that at the point of maximum pressure the chemical change concerned in the propagation of the wave is complete. The unburnt gases immediately in front of the waves are, of course, fired by compression, and the abrupt variation in the density and pressure of the medium is due to the chemical change. Chapman's formula for the velocity of the explosion wave in centimetres per second is

$$V=\sqrt{\frac{2RJ}{\mu C_v^2}[\{(m-n)C_p+mC_v\}C_pt_0+(C_p+C_v)h]},$$

where R = the gas constant (1·985), J = the dynamical equivalent of heat (42×10^6 ergs), μ = the gram equivalents of the mixture exploded (*e.g.*, 58 in the case of $C_2H_2+O_2$), n and m = the number of gaseous

[1] See his recent presidential address to the Chemical Society, *Trans. Chem. Soc.*, 1910, 97, 665.

[2] *Loc. cit.*, p. 152.

[3] *Phil. Mag.*, 1899, p. 90.

molecules before and after the chemical change in the wave, C_p and C_v = the mean specific heats of the products at constant pressure and volume respectively, h = the total heat generated in the wave, and t_0 = the initial temperature (abs.) of the mixture exploded. From the fact that the dilution of electrolytic gas $(2H_2+O_2)$ with oxygen lowers its rate of explosion a little more than a corresponding dilution with nitrogen, Chapman considers it improbable that there is any appreciable dissociation of steam in the wave. He assumes that the molecular heat of steam rises more rapidly with temperature than that of a diatomic gas, and that the molecular heats of oxygen, hydrogen, nitrogen, and carbon monoxide may for all practical purposes be considered as equal at any given temperature. Selecting some seventeen of Dixon's found rates of explosion, he has calculated by means of his formula the corresponding molecular heats and temperatures, arriving at the following results for C_v at intermediate temperatures by interpolation:—

		4300°	4000°	3700°	3400°	3100°	2800°	2500°
Temperature								
C_v	Steam	14·750	14·297	13·750	13·102	12·250	11·040	9·797
	Diatomic gases	7·707	7·674	7·641	7·608	7·575	7·542	7·509

With the aid of this series of numbers he proceeded to apply his formula to the calculations of the rates of explosion of some forty other mixtures investigated by Dixon, finding in all cases close agreement between the found and calculated values, of which the following may suffice as examples:—

Mixture exploded	Products in the Wave	Temp.	Rate of Explosion, Metres per Second	
			Calculated	Found
$2H_2+2N_2O$	$2H_2O+2N_2$	3813°	2,408	2,305
$4H_2+2N_2O$	$2H_2O+2N_2+2H_2$	3077°	2,604	2,545
$6H_2+2N_2O$	$2H_2O+2N_2+4H_2$	2612°	2,720	2,705
$2H_2+2N_2O+2N_2$	$2H_2O+4N_2$	3077°	2,097	1,991
$C_2H_4+2O_2$	$2CO+2H_2O$	4365°	2,619	2,581
$C_2H_4+3O_2$	$2CO+2H_2O+O_2$	3882°	2,348	2,368
$C_2H_2+O_2$	$2CO+H_2$	5029°	3,101	2,961
CH_4+O_2	$CO+H_2O+H_2$	2772°	2,502	2,528
$2CH_4+3O_2$	$2CO+4H_2O$	3764°	2,485	2,470
$2CH_4+3O_2+N_2$	$2CO+4H_2O+N_2$	3513°	2,353	2,349

A characteristic feature of detonation is the extremely short duration of chemical action and subsequent rapid cooling of the products, as compared with ordinary combustion. Some years ago the writer, working in conjunction with Bevan Lean, under Professor H. B. Dixon's direction, found by a photographic method that the duration of luminosity in each successive layer of gas in the detonation of electrolytic gas is certainly less than $\frac{1}{5000}$ second,[1] a much shorter interval of time than was required to shatter a tube of thin glass attached to the end of the explosion coil used. This tube, although invariably smashed by the force of the explosion,

[1] *Brit. Assoc. Report*, 1892.

always appeared perfectly intact in the photograph. Dixon's subsequent photographic researches have demonstrated the abrupt suddenness with which the gases attain the maximum temperature in detonation, the intensity and short duration of luminosity, and the subsequent rapid cooling, as compared with ordinary combustion. Moreover, high as is the temperature attained, there is no evidence of any considerable dissociation of steam in the wave, for, despite the instantaneous cooling of the products, there is less than one per cent. of the gases left uncombined after the wave has passed through electrolytic gas ($2H_2 + O_2$).

Influence of an Excess of an Inert Gas upon the Rate of Explosion.—Writing Chapman's formula as follows:—

$$V^2 = \frac{2RJ}{\mu C_v^2}[\{(m-n)C_p + mC_v\}C_p t_0 + (C_p + C_v)h]$$

and putting $\frac{2RJ}{\mu C_v^2} = A$, and the terms between the square brackets $= B$, it will be immediately perceived that the addition of an inert diatomic gas (*e.g.*, H_2, N_2, or O_2) to a given explosive mixture will affect the values of both A and B, but not necessarily in the same direction. It will increase the value of μ and diminish the values of C_v and C_p partly by lowering the temperature in the wave and partly also (if steam or carbon dioxide be formed in the wave) by reason of its own specific heat being lower than that of the undiluted products. It will also increase the value of m without altering $(m-n)$. If it be assumed that the molecular heats of the three diatomic gases under consideration are, for all practical purposes, equal at any given temperature, it will be at once seen that an equal dilution of a given explosive mixture, with any one of the three gases, whilst it will have an equal effect on all terms included under B, may either increase or diminish the value of A, according as to whether or not the *plus* effect of the lower value of C_v is counterbalanced by the *minus* effect of the increase in μ. If the latter effect be small, as would be the case with hydrogen as diluent, the value of A would on the whole be increased; whereas if the increase in μ were large, as would be the case with nitrogen or oxygen as the diluent, the value of A would on the whole be diminished.

As an example of the probable effects of the equal dilution of a given explosive mixture with each of the three gases in question, the case of an equimolecular mixture of hydrogen and nitrous oxide, fired at 10° and 760 mm., may be cited as follows:—

Mixture	h	m	$m-n$	μ	C_v	Temp.	A	B	V. in Metres per Second	
									Calculated	Found
$H_2 + N_2O$ . .	152,500	4	0	92	10·81	3813°	15,640	3,758,750	2,425	2,305
$H_2 + N_2O + 2H_2$		6	0	96	9·10	3077°	20,980	3,251,500	2,612	2,545
$H_2 + N_2O + 2N_2$		6	0	148	9·10	3077°	13,610	3,251,500	2,104	1,991
$H_2 + N_2O + 2O_2$		6	0	156	9·10	3077°	12,830	3,251,500	2,042	—

An inspection of the figures under columns A and B will at once make it clear why, whereas dilution with hydrogen is invariably found to increase the rate of explosion of a given mixture, an equal dilution with nitrogen or oxygen invariably diminishes it, and also why the retarding influence of oxygen must always be greater than that of an equal proportion of nitrogen. The following examples, taken from Dixon's memoir, may be cited in support of the above argument:—

Effects of Dilution upon the Rate of Explosion of Electrolytic Gas.

Mixture Exploded	Rate Metres per Sec.
$2H_2 + O_2$	2,817
$2H_2 + O_2 + 2H_2$	3,268
$2H_2 + O_2 + 4H_2$	3,527
$2H_2 + O_2 + 6H_2$	3,532
$2H_2 + O_2 + O_2$	2,328
$2H_2 + O_2 + 3O_2$	1,927
$2H_2 + O_2 + N_2$	2,426
$2H_2 + O_2 + 3N_2$	2,055

Effects of Dilution with Hydrogen upon the Rate of Explosion of Hydrogen and Chlorine.

Mixture	$H_2 + Cl_2$	$2H_2 + Cl_2$	$3H_2 + Cl_2$
Rate	1,729	1,849	1,855 metres per sec.

The Burning of Gaseous Carbon.—Of the many important facts brought to light during the course of Dixon's investigation none are of greater interest than those relating to the burning of gaseous carbon in the explosion wave, as illustrated by the case of cyanogen. In view of the fact that the molecular heat of combustion of cyanogen, when burnt completely to carbon dioxide, is 259·6 kilogram C. units, whereas, if burnt to the monoxide, it would only be 123 units, it might be expected that the rate of explosion for a mixture $C_2N_2 + 2O_2$ would be much higher than for $C_2N_2 + O_2$, if gaseous carbon is primarily burnt to carbon dioxide in the wave. The exact opposite is the case, however, as the following results show:—

Mixture	Products	Rate	
$C_2N_2 + O_2$	$2CO + N_2$	2,728	metres per sec.
$C_2N_2 + 2O_2$	$2CO_2 + N_2$	2,321	

Still more cogent is the evidence in favour of the initial formation of carbon monoxide in the wave, when the following figures are considered:—

	$C_2N_2 + O_2$	$C_2N_2 + O_2 + N_2$	$C_2N_2 + O_2 + O_2$
Rate	2,728	2,398	2,321

The conclusion to be drawn from the preceding figures is that cyanogen is initially burnt to carbon monoxide and nitrogen in the wave itself, any excess of oxygen afterwards burning up the carbon monoxide as the gases cool down in the rear of the wave.

This conclusion was driven home by Dixon, in conjunction with Strange and Graham, by photographing on a sensitive film, rotated at

a speed of about 1,500 metres per minute, the explosion flame in the case of the three mixtures (*a*) $C_2N_2+O_2$, (*b*) $C_2N_2+O_2+N_2$, and (*c*) $C_2N_2+2O_2$. In each case the flame was photographed, after detonation had been set up, as it dashed past a glass window inserted into the lead explosion coil.[1] The image obtained in the case of (*a*) showed an intensely brilliant flame (the explosion wave), slightly drawn out in tapering form; in the case of (*b*), with nitrogen as diluent, the flame was less brilliant and somewhat more drawn out than in (*a*); but with (*c*) the flame, whilst no more luminous than in (*b*), was drawn out to great length, owing to the continued combustion of carbon monoxide in the rear of the wave. The following diagram, fig. 4 (approximately to scale), will convey an idea of the relative durations of the flames in the three cases:—

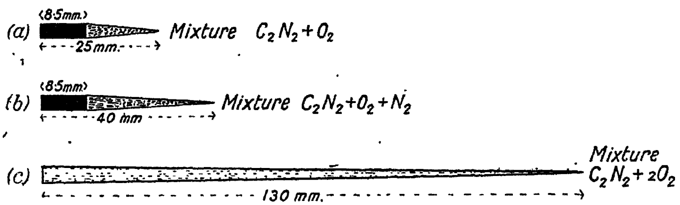

FIG. 4.

The Burning of Hydrocarbons in the Wave.—It was during the course of measurements of the rates of explosion of hydrocarbons with varying proportions of oxygen in 1891-92 that Dixon and his collaborators rediscovered facts (originally set forth by Dalton in his 'New System of Chemical Philosophy') which finally disposed of the dogma that in a deficient supply of oxygen a 'selective' burning of hydrogen occurs. It was found that when either ethylene or acetylene is detonated with its own volume of oxygen the ultimate products consist almost entirely of carbon monoxide and hydrogen.[2] The rates of explosion, whilst they do not reveal the real mechanism of the combustion, show very clearly that, as in the case of cyanogen, the carbon of a hydrocarbon is burnt initially to the monoxide in the wave itself, the formation of the dioxide being an after-effect and taking place in the rear of the wave. In the cases of methane and acetylene the fastest rates are observed with equimolecular mixtures, whereas with ethylene the rate increases with the proportion of oxygen up to the limit $C_2H_4+2O_2$. As the question of the mechanism of hydrocarbon combustion will be fully discussed later, the following rates of explosion, as determined by Dixon, may now be given without further comment:—

(A) *Methane and Oxygen in Varying Proportions, fired at* 10° *and* 760 *mm.*

Mixture	CH_4+O_2	$CH_4+1\frac{1}{2}O_2$	CH_4+2O_2	CH_4+3O_2*	CH_4+4O_2
Rate in metres per sec.	2,528	2,470	2,322	2,146	1,963

* Compare this with the 2,154 metres per sec. observed for $CH_4+1\frac{1}{2}O_2+1\frac{1}{2}N_2$ as showing the inertness of at least the moiety of the oxygen in the wave.

[1] *Trans. Chem. Soc.*, 1896, 69, 759.

[2] *Vide* Lean and Bone, *Trans. Chem. Soc.*, 1892, 61, 873, and Bone and Cain, *ibid.*, 1897, 71, 26.

(B) *Ethylene and Oxygen in Varying Proportions, fired at 10° and 760 mm.*

Mixture	$C_2H_4+O_2$	$C_2H_4+2O_2$	$C_2H_4+3O_2$*	$C_2H_4+4O_2$	$C_2H_4+6O_2$
Rate in metres per sec.	2,507	2,581	2,368	2,247	2,118

* Compare this with the 2,413 metres per sec. observed for $C_2H_4+2O_2+N_2$.

(C) *Acetylene and Oxygen in Varying Proportions, fired at 10° and 760 mm.*

Mixture	$C_2H_2+O_2$	$C_2H_2+1\frac{1}{2}O_2$	$C_2H_2+2\frac{1}{2}O_2$*
Rate in metres per sec.	2,916	2,716	2,391

* Compare this with the 2,414 metres per sec. observed for $C_2H_2+1\frac{1}{2}O_2+N_2$.

SECTION III.—*The Pressures produced by Gaseous Explosions.*

Many investigators, from the time of Bunsen's well-known experiments in 1867 onwards, have measured the pressures produced in gaseous explosions, with doubtless considerable success so far as what may be termed the mean effective pressures are concerned. As the subject is at present engaging the attention of a Committee appointed by the Association in 1907 any lengthy reference to it in this report may seem superfluous. Nevertheless, if only for the sake of completeness, a brief *résumé* of our present knowledge may not be out of place. The explosion vessel employed by Bunsen was a stout glass tube 8·15 cm. long, 1·7 cm. internal diameter, and of 18 c.c capacity. It was closed by a suitable valve, the load on which could be adjusted until it was just lifted when the explosive mixture was fired by means of a powerful spark passed along the axis of the tube. Bunsen considered that the combustion would occur under adiabatic and 'constant volume' conditions, and he identified the rate of ignition of a particular mixture with that of the completion of chemical change. In calculating from his results the corresponding flame temperatures he assumed the constancy of the specific heats of steam and carbon dioxide. Finding that the pressures recorded in the cases of electrolytic gas and of a mixture of carbon monoxide and oxygen in their combining proportions (namely, 9·5 and 10·1 atmospheres respectively) were somewhat less than one-half of those theoretically required on the above assumptions, he concluded that in each case combustion had proceeded *per saltum*, owing to the supposed theoretical flame temperatures exceeding the limits at which steam and carbon dioxide respectively are completely dissociated. The problem was again attacked independently by Mallard and Le Chatelier in 1883,[1] and by Berthelot and Vieille in 1885.[2] The last-named fired various gaseous mixtures at atmospheric pressure in a spherical iron bomb, measuring the effective pressures by the movement of a light piston working against a spring in a tube attached to the bomb. In order to gain some information respecting the possible cooling influence of the walls upon the effective pressures recorded, three bombs of different capacities—namely, A of 300 c.c., B of 1,500 c.c., and C of 4,000 c.c.—were employed. The results, expressed in each case as atmospheres in excess of the atmospheric pressure, were as follows:—

[1] *Annales des Mines*, Sec. viii., vol. 4. [2] *Ann. Chim. Phys.* [vi.], 4, 13.

Bomb		A	B	C
Capacity in cm.^{3}		300	1,500	4,000
Surface in cm.^{2}		216	648	1,220
Surface per unit volume		0·72	0·43	0·33
Diameter in cm.		6·0	14·2	21·7
Length of firing piece in cm.		6·3	5·3	6·3
Travel of flame before reaching the piston in cm.		9·1	16·3	24·8
		Atms.	Atms.	Atms. (Pressures)
Mixture exploded	$2H_2+O_2$	7·41	9·69	9·80
	$2CO+O_2$	9·29	9·93	10·21
	CH_4+2O_2	13·94	14·81	16·31
	$C_2N_2+O_2$	—	—	25·11
	$C_2N_2+2O_2$	—	—	20·96
Time required for flame to travel from the firing piece to piston of indicator.				
Mixture	$2H_2+O_2$	0·00104 sec.	—	0·00214 sec.
	$2CO+O_2$	0·01286 sec.	—	0·01551 sec.

Perhaps the most notable feature about these results is the smallness of the difference between the pressures observed with bombs A and C in any particular case. These differences might at first sight be attributed to the (supposed) much smaller cooling influence of the walls of the bomb C as compared with bomb A, but if this were the true explanation the difference should be greater with the slow-burning $2CO+O_2$ mixture than with the fast-burning $2H_2+O_2$, whereas the opposite was the case. Moreover the fact that dilution of the mixture $2H_2+O_2$ with twice its own volume of nitrogen almost obliterated the difference between the pressures observed in the cases of bombs A and C (the ratio $\frac{pC}{pA}$ for the diluted being 0.95, as against 0·76 for the undiluted mixture) is all against the cooling theory. The more probable explanation is to be found in the fact that, owing to the much longer travel of the flame before it reached the piston of the indicator in bomb C as compared with A, the explosion would be in a more advanced phase of its development, and this would be most marked in the case of the fastest burning mixtures. Berthelot and Vieille assumed that in the above experiments completion of the combustion synchronised with the attainment of maximum pressure, and attributed the marked disparity between the observed pressures (bomb C) and those calculated from the heats of combustion (on the assumption of adiabatic conditions) to a rapid increase in the specific heats of steam and carbon dioxide at high temperatures. They considered it improbable that dissociation phenomena play any conspicuous part in limiting the pressures attained.

Mallard and Le Chatelier,[1] who used a Bourdon gauge for measuring pressures and applied a ' cooling correction ' to their results, arrived at practically the same conclusion as Berthelot and Vieille [2] respecting both

[1] *Loc. cit.* [2] *Ann. Chim. Phys.* [vi.], 4, 13.

the increase of the specific heats of steam and carbon dioxide with temperature and the small if not negligible influence of dissociation. They calculated that the temperature of the flame when moist electrolytic gas is exploded in a closed vessel at atmospheric pressure is about 3350°, and that the mean molecular heat of steam at constant volume between 0° and 3350° is 16·6. In the case of the mixture $2CO + O_2$ they concluded that the molecular heat (C_a) of carbon dioxide rises to 13·6 at 2000°, above which temperature dissociation comes into play.

The experience of all subsequent investigators has confirmed that of Bunsen and the French savants, in so far as the facts of the case are concerned. It may be taken as commonly agreed that the maximum effective pressures recorded when gaseous mixtures are fired in closed vessels are always considerably less than those calculated on the assumption that the whole heat of combustion is communicated without loss to the products, and that the specific heats of the products do not vary with temperature. Thus in the case of Mr. Dugald Clerk's experiments, where hydrogen and air mixtures were exploded at atmospheric pressure in a closed cylindrical vessel 21 cm. long, 17·75 cm. diameter, and 5·2 litres capacity, the maximum pressures, recorded by a Richards' indicator making a graph on a revolving drum, varied between about 50 and 60 per cent. of those calculated on the above assumptions, as follows:—

Mr. Dugald Clerk's Experiments (1884–85).

	Vols. Air to 1 Vol. Hydrogen 2½	4	6	
Maximum pressure found . .	6·44 . .	5·63 . .	3·80	Atmo-spheres
Maximum pressure calculated on the above assumptions . .	13·0 . .	9·45 . .	7·0	

Another feature (since confirmed by many subsequent observers) brought out by Mr. Clerk's experiments was the very short time required for the attainment of maximum pressure relative to the subsequent cooling period. Thus in the case of the mixture of 1 vol. hydrogen with 4 vols. air, the maximum pressure of 68 lb. per square inch above the atmospheric was attained in 0·026 sec., whereas the subsequent cooling period occupied 1·05 sec., or forty times as long.

The great disparity between the found and 'calculated' maximum pressures has been attributed by the various investigators concerned to one or other of the following causes, namely:—

1. *To the marked increase in the specific heats of steam and carbon dioxide with temperature.* That this is a true cause is now generally admitted; as, however, the subject was fully dealt with in the first report of the Committee appointed by the Association in 1907 for the investigation of gaseous explosions, it need not be considered in any detail here.

2. *To the fact that in ordinary gaseous explosions, where detonation has not been determined, combustion is by no means instantaneous, and may not be completed within the period required for the attainment of*

maximum pressure. Mr. Dugald Clerk put forward this suggestion as long ago as 1886 [1] in criticising the conclusions of Mallard and Le Chatelier respecting the great increase in the specific heats of steam and of carbon dioxide with temperature. He considered it highly probable that combustion extends far into the actual 'cooling period' in gaseous explosions (and hence the long drawn out 'cooling curve'), so that the system loses a certain part of the heat of combustion before the chemical action is completed. This idea of a continued combustion finds support in H. B. Dixon's photographic researches, and chemists generally will concede its reality in any gaseous combination in which detonation is not determined. But to what extent it may be held to affect the pressures actually recorded by explosions is still a matter of conjecture.

3. *To loss of energy by direct radiation.* Thus in the explosion of a mixture of hydrogen and oxygen it is conceivable that the *initial* action results in the formation of an intensely vibrating molecular complex from which steam issues as the first recognisable product. Some experiments made in 1890 by Robert von Helmholtz [2] showed that non-luminous hydrocarbon flames radiate about 5 per cent. of the heat of combustion of the gas, and more recent experiments by Professor Callendar and Mr. Nelson show that the heat radiated from an ordinary non-luminous Bunsen flame may amount to between 15 and 20 per cent. of the total heat of combustion, a figure which is in close agreement with the results of experiments carried out by Mr. E. W. Smith under the auspices of the Gas-Heating Research Committee appointed by the Institution of Gas Engineers in conjunction with the University of Leeds.[3] There is, therefore, little doubt but that this cause is truly operative in gaseous explosions.

4. *To dissociation of products* (steam and carbon dioxide). In the case of two combining gases producing a dissociable product, it is clear that if the average temperature in the system reaches that at which dissociation begins the combustion must be delayed whilst heat escapes from the system by radiation and conduction. Qualitatively the partial dissociation of steam and carbon dioxide has been proved at temperatures which are certainly exceeded by those of explosion flames, but it may be urged that, inasmuch as all experiments upon dissociation have up to the present involved contact with hot solid surfaces, there is no positive evidence that the phenomenon would play any conspicuous part in an unconfined gaseous system. On the other hand, there is direct experimental evidence of the attainment of enormously high temperatures in the explosion wave, temperatures which would generally be considered as far beyond that of the initial, or perhaps even of the complete, dissociation of steam or of carbon dioxide. Moreover, the fact that the rate of explosion of electrolytic gas is retarded rather more by an excess of oxygen than by a corresponding excess of nitrogen is inconsistent with the supposition of any appreciable dissociation of steam in the explosion wave, and photographic records give no evidence of continued

[1] *Proc. Inst. Civil Engineers*, 85.
[2] *Beiblätter*, 14, 589.
[3] See pp. 10–13 of the Committee s Second Report, 1910.

combination in the rear of the wave except where there are two or more chemical stages in the combustion.

SECTION IV.—*The Influence of Moisture upon Combustion.*

Thirty years ago H. B. Dixon, in repeating Bunsen's experiments on the division of oxygen between carbon monoxide and hydrogen, both present in excess, discovered that a mixture of carbon monoxide and oxygen, dried by long contact with phosphoric anhydride, will not explode when sparked in the usual way in a eudiometer, whereas the presence of a trace of moisture or of any gas containing hydrogen (*e.g.*, methane, ammonia, or hydrogen chloride) at once renders the mixture explosive. These experiments, proving as they did the complexity of what at first sight would appear to be one of the simplest cases of combustion, opened up a new field of scientific investigation.

In 1883 H. B. Baker, working in Dixon's laboratory at Balliol College, Oxford, found that purified charcoal, when heated to redness in carefully dried oxygen, burns with extreme slowness and without flame, yielding principally the monoxide, the proportion of the dioxide formed varying inversely with the degree of dryness of the oxygen. In a further series of experiments he proved that highly purified sulphur or phosphorus may be repeatedly distilled in an apparatus filled with carefully dried oxygen, without any combustion whatever occurring, although the admission of even a trace of moisture at once causes a vivid burning. In subsequent investigations extending over a number of years, Baker has shown that a large number of gaseous interactions are either conditioned or greatly accelerated by the presence of moisture. Thus a dried mixture of hydrogen and chlorine does not explode on exposure to sunlight, dried ammonia and hydrogen chloride are mutually inert, and dried electrolytic gas, free from hydrocarbon impurity, can be heated to redness without exploding.

The amount of moisture required to bring about such chemical changes as the above is surprisingly small. E. W. Morley has estimated that the mere passing of a gas through a long column of phosphoric anhydride leaves only 3 milligrams of water vapour in a million litres (or rather less than 4 molecules of steam per 1,000 million molecules of gas), and yet a much more prolonged drying is usually required to inhibit chemical action. Such facts as these, even if they do not raise doubts as to the adequacy of the usually accepted kinetic views of chemical processes, at least suggest the necessity of some less stringent application of them.

The dependence of the combustion of carbon monoxide upon the presence of water vapour is well illustrated by H. B. Dixon's determination of the rates of explosion for mixtures of carbon monoxide and oxygen in combining proportions containing varying amounts of water vapour. Starting with a 'well-dried' mixture, the rate of explosion increases with successive additions of moisture, from 1,264 to a maximum of 1,738 metres per second for a mixture saturated at 35°, any further addition of steam having a decidedly retarding influence, as follows:—

Rates of Explosion, at 10° and 760 mm., for a mixture $2CO+O_2$ containing varying Proportions of Steam.

Hygroscopic Condition	Per Cent. Moisture	Rate in Metres per Second
Well dried	—	1,264
Saturated at 10°	1·2	1,676
„ 20°	2·3	1,703
„ 28°	3·7	1,713
„ 35°	5·6	1,738
„ 45°	9·5	1,693
„ 55°	15·5	1,666
„ 65°	24·6	1,526
„ 75°	38·0	1,266

Before entering upon a discussion of the theoretical aspects of the matter, certain other facts must be considered, namely:—

1. In the detonation of a dried mixture of cyanogen with twice its own volume of oxygen the formation of carbon dioxide is complete; moreover, under such conditions it has been proved that carbon monoxide is primarily formed in the wave itself, the second stage of the combustion—namely, $2CO+O_2=2CO_2$—taking place in the rear of the wave.[1]

2. A well-dried mixture of carbon monoxide (36 per cent.), ozone (8 per cent.), and oxygen cannot be fired with a powerful electric spark; also, on sparking a well-dried mixture of carbon monoxide (60 per cent.), chlorine peroxide (29 per cent.), and oxygen (11 per cent.), although a flame is propagated through the gases, as much as 76 per cent. of the original carbon monoxide may remain unburnt.[2]

3. Dried carbon monoxide and oxygen completely combine without flame in contact with a heated platinum wire; moreover, the writer has recently proved that the most careful drying possible greatly accelerates the rate at which the gases combine in contact with a hot fire-clay surface at 500°.

4. There are certain well-established instances in which combustion is not determined by the presence of moisture—namely, the combustion of cyanogen, of carbon disulphide, and of hydrocarbons (ethane, ethylene, and acetylene).

Theories respecting the Function of Moisture.

1. H. B. Dixon has consistently maintained that, in the combustion of carbon monoxide, steam merely acts as the carrier of oxygen; he contends that in explosions the formation of carbon dioxide is always limited by its dissociation, and that at the highest temperature (*e.g.*, in the wave-front when the mixture $C_2N_2+2O_2$ is detonated) it is not formed at all by *direct* interaction of the monoxide and oxygen, because the internal energy which would thereby be imparted momentarily to the newly-born dioxide molecule would bring about its dissolution. For the

[1] H. B. Dixon.
[2] H. B. Dixon and E. J. Russell, *Trans. Chem. Soc.*, 1897, 71, 605.

same reason flame is not propagated through a dried mixture of carbon monoxide and oxygen. But, if steam be present, the interaction of $CO + OH_2 = CO_2 + H_2$ would bring molecules of the dioxide into existence with a much less degree of internal agitation, and therefore capable of continued existence, whilst the hydrogen liberated would immediately combine with oxygen, forming steam, which is less easily dissociated than carbon dioxide. This explanation, whilst consistent with many of the facts connected with the combustion of carbon monoxide, cannot be extended to other well-known instances, and is particularly inapplicable to the case of hydrogen.

2. Mendelejeff, in his 'Principles of Chemistry,' ascribed the mutual inertness of carbon monoxide and oxygen to the circumstance that gases combine according to a supposed '*law of equal volumes*,' or, in other words, that from the kinetic standpoint the primary changes in all cases must be considered as involving the collision of two molecules only. In the case of carbon monoxide he postulated the following cycle of changes:—

$$\text{(i) } CO + OH_2 = CO_2 + H_2\text{; (ii) } H_2 + O_2 = H_2O_2\text{; (iii) } CO + O_2H_2 = CO_2 + OH_2.$$

But, according to this supposed '*law of equal volumes*,' a well-dried mixture of carbon monoxide and nitrous oxide, or of carbon monoxide and ozone, should be active, whereas Dixon has proved them to be as non-explosive as a dried mixture of the monoxide and oxygen.

3. H. E. Armstrong has always contended that chemical actions cannot occur between two perfectly pure substances, but require the conjunction of an electrolyte in order to form a closed conducting system. The presence of steam, which he supposes may always be regarded as rendered 'conducting' by association with some traces of an electrolyte impurity, provides the necessary conditions for the passage of the current, the oxygen playing the part of depolariser, thus:—

$$\begin{array}{c|c|c} \multicolumn{3}{c}{\text{Before.}} \\ O & H_2O & CO \\ | & & \\ O & H_2O & CO \end{array} \longrightarrow \begin{array}{c|c} \multicolumn{2}{c}{\text{After.}} \\ OH_2 & OCO \\ & OCO \\ OH_2 & \end{array}$$

On the other hand, H. B. Dixon has urged that a rate of explosion of nearly 1,700 metres per second for a moist mixture of carbon monoxide and oxygen is incompatible with any interaction of the complexity thus postulated. There is doubtless *prima facie* much force in this objection, but it is by no means fatal, seeing that the dimensions of the explosion wave are incomparably greater than molecular units, and the duration of chemical action, though extremely short when measured in terms of ordinary gross units of time, is at least many thousands of times greater than the intervals between successive molecular collisions.[1] A more serious objection to Armstrong's theory is the fact that there are

[1] As the writer understands Dixon's objection to Armstrong's view, it is that whilst chemical action in the explosion wave may *last* a comparatively long time (*i.e.*, during many molecular collisions), and that therefore a quintuple molecular collision might happen in that period, it is impossible for the wave to be *propagated* as a sound-wave through quintuple collisions. Ordinary sound-waves may be many molecules *thick*, but they are propagated through bi-molecular collisions.

several well-established cases in which combustion apparently does not depend upon the presence of moisture.

4. In 1893 Sir J. J. Thomson [1] pointed out that if the forces holding the atoms together in a molecule are electrical in character, the presence of drops of any liquid (such as water) of high specific inductive capacity would probably cause a sufficient loosening of the bands between the atoms to render the molecule much more reactive. He showed that the complete drying of a gas renders it non-conductive. H. B. Baker, in his Wilde Lecture before the Manchester Literary and Philosophical Society,[2] described a number of new experiments which led him to put forward tentatively the theory that chemical interchanges in gaseous systems depend upon the presence of both 'ions' and water vapour; the 'ions' act as nuclei for the condensation of steam, and the liquid drops of water so formed, by virtue of their high specific inductive capacity, facilitate chemical change in the layer of gas immediately in contact with them. Chemists will await with the greatest interest the further development of this hypothesis, but the idea that such rapid changes as are met with in gaseous explosions are dependent upon the formation of *aggregates* of steam molecules in an atmosphere containing fewer than four of them per 1,000 millions, and that such aggregates approximate to *liquid drops* at the high temperatures of flames, makes large demands upon the imagination, and it will require to be supported by the strongest experimental evidence.

Section V.—*The Combustion of Hydrocarbons.*

The question of how a hydrocarbon is attacked by oxygen in combustion has been the subject of much controversy during the past twenty years, but it is only quite recently that experimental inquiry has been pushed far enough to justify the advancement of any complete theory of the process.

Throughout the greater part of last century it was accepted as an article of faith among chemists that hydrogen is the more combustible element of a hydrocarbon; thus, as late as 1884 H. B. Dixon, in his Cantor lectures on 'The Use of Coal Gas,' speaking of the combustion of ethylene in its bearing on the luminosity of hydrocarbon flames, said: '*This ethylene, when it is raised to a high temperature in contact with air, is decomposed, the hydrogen burning first and the carbon afterwards. There is a race for the oxygen of the air between the two constituents of the ethylene, and the hydrogen, being the fleeter of the two, gets to the oxygen first, and is burnt to water.*' Eight years later, when it was discovered in Dixon's laboratory that an equimolecular mixture of ethylene and oxygen yields on detonation almost exactly twice its own volume of carbon monoxide and hydrogen, [3] in accordance with the empirical equation

$$C_2H_4 + O_2 = 2CO + 2H_2,$$

[1] *Phil. Mag.*, **36**, 321.

[2] *Man. Mem.*, **53**, part iii.

[3] H. B. Dixon, *Phil. Trans.*, 1893, 159; also Lean and Bone, *Trans. Chem. Soc.*, 1892, **61**, 873.

and also when Smithells and Ingle, about the same time, in their researches on the Structure and Chemistry of Flames, discovered hydrogen in the interconal gases of aërated hydrocarbon flames,[1] the dogma of the preferential combustion of hydrogen became untenable. Attempts were then made to revive an idea originally put forward by Kersten in 1861—namely, that '*before any part of the hydrogen is burnt all the carbon is burnt to carbonic oxide, and that the excess of oxygen (if any) divides itself between the carbonic oxide and hydrogen.*' H. B. Dixon was himself inclined to this view, and Smithells spoke of the 'preferential' burning of carbon both in his 1892 paper and in his lecture on 'Flame' at the Nottingham meeting of the Association in 1893, although he has since disclaimed any intention of exalting the idea into a general doctrine.

The idea of a 'selective' combustion, whether of carbon or of hydrogen is, however, so repugnant to well-established principles that it could hardly be expected to meet with general acceptance in any final or complete sense, and there were many sceptics as to its validity. Moreover, whilst in the cases of acetylene and ethylene the assumption of a *direct* transition from the system $C_nH_m + \frac{n}{2}O_2$ to $nCO + \frac{m}{2}H_2$ implies a simple transaction from the kinetic standpoint, an extension of the idea to the cases of such hydrocarbons as propane or propylene would obviously raise serious difficulties,

$$2C_3H_8 + 3O_2 = 6CO + 8H_2,$$
$$2C_3H_6 + 3O_2 = 6CO + 6H_2.$$

It therefore seemed necessary to consider whether the solution of the problem might not lie in the assumption of an initial association of the hydrocarbon and oxygen forming an unstable 'oxygenated' or 'hydroxylated' molecule, as suggested by H. E. Armstrong many years ago, and it was with some such possibility in view that the writer undertook the re-investigation of the subject about ten years ago.

Previous workers had confined their attention to combustion at such high temperatures as prevail in hydrocarbon flames and the explosion wave—conditions highly unfavourable to the detection or isolation of unstable intermediate 'oxygenated' products, if such are really formed. It was therefore decided first of all to make a systematic study of hydrocarbon combustion at temperatures below the ignition-points of the mixtures used, where the rate of oxidation would be much slower and more controllable, and intermediate products more stable. The hydrocarbons selected for investigation were methane, ethane, ethylene, and acetylene, and at the outset of the work it was fortunately discovered that all four gases combine with oxygen at temperatures much below those at which either hydrogen or carbon monoxide begin to be oxidised with any appreciable velocity, or at which either carbon reduces steam or the reversible reaction $CO + OH_2 = CO_2 + H_2$ could have any influence whatever upon the result. Conditions were thus established which precluded the interference of secondary processes with the main line of change.

[1] Smithells and Ingle, *Trans. Chem. Soc.*, 1892, 61, 209.

The first experimental method consisted in maintaining mixtures of each hydrocarbon with varying proportions of oxygen, sealed up in borosilicate glass bulbs of about 60 c.c. capacity, at known constant temperatures between 250° and 350°, for definite periods of time. Subsequently an apparatus was devised in which large volumes of the reacting mixtures could be circulated at a uniform speed in a closed system comprising (1) a surface of porous porcelain maintained at a constant temperature in a combustion furnace, (2) suitable cooling and washing arrangements for the removal of condensable or soluble intermediate products, and (3) a mercurial manometer for recording pressures.

By means of these two experimental methods it was proved, as regards slow combustion—(1) that a hydrocarbon is ultimately burnt to a mixture of steam and oxides of carbon without any separation of carbon or liberation of hydrogen at any stage of the process; (2) that the oxidation is marked by a very large intermediate formation of aldehydic products; (3) that the fastest rates of oxidation are (in the cases of the four hydrocarbons examined) always obtained with a ratio of hydrocarbon to oxygen between 2 : 1 and 1 : 1, an excess of oxygen above the equimolecular ratio always having a marked retarding influence; and (4) that a large proportion of carbon dioxide is often found in the products under conditions which preclude all possibility of its formation either by the direct oxidation of the monoxide or by the interaction of the monoxide with steam.

Finally, the balance of evidence was so overwhelmingly in favour of the supposition that combustion had proceeded by successive stages of 'hydroxylation' that the following schemes were put forward for the typical hydrocarbons ethane, ethylene, and acetylene:—

$$\underset{\text{Ethane}}{CH_3.CH_3} \rightarrow \underset{\text{Ethyl Alcohol}}{CH_3.CH_2OH} \rightarrow \underbrace{CH_3.CH(OH)_2}_{\underset{\text{Acetaldehyde}}{CH_3.CHO+H_2O}} \rightarrow CO+H_2O+\underset{\text{Formaldehyde}}{H.CHO} \rightarrow \underbrace{\overset{\text{Formic Acid}}{H.COOH}}_{CO+H_2O} \rightarrow \underbrace{\overset{\text{Carbonic Acid}}{CO(OH)_2}}_{CO_2+H_2O}$$

$$\underset{\text{Ethylene}}{H_2C{:}CH_2} \rightarrow \underset{\text{Vinyl Alcohol}}{H_2C{:}CH(OH)} \rightarrow \underbrace{HO.HC{:}CH.OH}_{\underset{\text{Formaldehyde}}{2H.CHO}} \rightarrow \underbrace{H.COOH}_{CO+H_2O} \rightarrow \underbrace{CO(OH)_2}_{CO_2+H_2O}$$

$$\underset{\text{Acetylene}}{HC{\vdots}CH} \rightarrow HO.C{\vdots}CH \rightarrow \underbrace{HO.C{\vdots}C.OH}_{CO+H.CHO} \rightarrow \underbrace{H.COOH}_{CO+H_2O} \rightarrow \underbrace{CO(OH)_2}_{CO_2+H_2O}$$

In other words, the attack of the oxygen upon the hydrocarbon may be supposed to involve a series of successive 'hydroxylations,' the hydroxylated molecules either breaking down or undergoing further oxidation, according to their relative stabilities and affinities for oxygen at the particular temperature, substantially as represented by the above schemes.

It should be mentioned, however, that whilst in many of the 'circulation' experiments a very large proportion of the intermediate aldehydic products were successfully removed from the sphere of action before undergoing further oxidation—*e.g.*, as much as 92 per cent. of the formaldehyde indicated at the third stage of the ethane scheme, and

45 per cent. of that required at the second stage of the ethylene scheme —in none of the experiments was it found possible to detect or isolate any of the *monohydroxy* derivatives which are, *ex hypothesi*, initially formed. This was perhaps hardly to be expected in the cases of ethylene or acetylene, where the monohydroxy derivative would be extremely unstable. In the case of ethylene, however, acetaldehyde, which is known to be readily formed by molecular rearrangement from vinyl alcohol, was isolated in certain experiments. But failure to detect the formation of ethyl alcohol during the slow oxidation of ethane did at first sight seem a serious obstacle to the acceptance of the 'hydroxylation' theory. This difficulty was, however, largely removed when it was subsequently found that ethyl alcohol is oxidised at a much faster rate than is ethane under like conditions—a circumstance which seems to warrant the view that the effect of the initial 'hydroxylation' of the hydrocarbon is to render the molecule much more susceptible to further attack. Finally, when Drugman, working in the writer's laboratory, obtained direct proof of the large formation of ethyl alcohol as the result of the interaction of ethane and ozone at 100°, the difficulty referred to entirely disappeared. Moreover there is strong indirect proof of the initial formation of monohydroxy derivatives during slow combustion in the fact that whereas the rates of oxidation observed with mixtures containing two molecules of hydrocarbon to one molecule of oxygen were hardly, if at all, inferior to those observed with equimolecular mixtures, the process was always much retarded by any further addition of oxygen beyond the equimolecular ratio. It may also be urged that the hydroxylation theory readily explains the large formation of carbon dioxide in the bulb experiments under conditions which would entirely preclude the idea of its formation by the direct oxidation of the monoxide or as the result of interaction of the monoxide with steam.

The next step in the inquiry was to ascertain whether the presence of moisture is essential to hydrocarbon combustion. A series of careful experiments on mixtures of the three typical hydrocarbons respectively with oxygen in equimolecular proportions thoroughly dried by long contact with redistilled phosphoric anhydride, under conditions which (as was proved) inhibited the formation of steam from electrolytic gas, gave wholly negative results. If anything, combustion occurred rather more readily with the dried gases than in the case of the corresponding experiments with undried mixtures. Therefore, whilst the conclusion finally advanced concerning the mechanism of hydrocarbon combustion agrees with the view originally put forward by H. E. Armstrong, in so far as the nature of the intermediate products is concerned, it differs from his in supposing that the oxygen is *directly* active.

With the extension of the investigation to hydrocarbon flames and explosions, including 'detonation' and explosions under high initial pressures, it became increasingly evident that the mechanism of combustion is essentially the same above as below the ignition-point, in so far as the result of the initial molecular encounters between hydrocarbon and oxygen is concerned. At the higher temperatures of flames secondary thermal decompositions undoubtedly come into operation at

an earlier stage than in slow combustion, but they do not precede the onslaught of the oxygen upon the hydrocarbon, as was formerly supposed, but arise in consequence of it.

In considering explosive combustion, therefore, it is necessary to take into account the possible modes of decomposition of the hydroxy derivatives formed in the first two stages of slow combustion, because these derivatives are so manifestly unstable at the high temperatures of flames that they would at once break down into simpler products. *Ethyl alcohol*, it is known, decomposes into ethylene and steam; *acetaldehyde* into methane and carbon monoxide, or into carbon, hydrogen, methane, and carbon monoxide, according to the temperature; *formaldehyde* is resolved into carbon monoxide and hydrogen without the slightest separation of carbon. Thus:—

$$\begin{array}{ccc}
\text{Ethyl Alcohol} & \text{Acetaldehyde} & \text{Formaldehyde} \\
\underbrace{C_2H_5.OH}_{C_2H_4+H_2O} & \underbrace{CH_3.CHO}_{\left\{\begin{array}{c} CH_4+CO \\ C+2H_2+CO \end{array}\right\}} & \underbrace{H.CHO}_{CO+H_2}
\end{array}$$

Therefore, taking as examples the typical cases of ethane and ethylene, the scheme for explosive combustion becomes

$$\begin{array}{ccccc}
H_3C.CH_3 & \rightarrow & \overset{1}{\underbrace{H_3C.CH_2OH}_{C_2H_4+H_2O}} & \rightarrow & \overset{2}{\underbrace{H_3C.CH(OH)_2}_{\underbrace{H_3C.CHO+H_2O}_{\left\{\begin{array}{c} CH_4+CO \\ C+H_2+CO \end{array}\right\}}}} \\
H_2C{:}CH_2 & \rightarrow & \overset{1}{\underbrace{H_2C{:}CHOH}_{2C+H_2+H_2O}} & \rightarrow & \overset{2}{\underbrace{HO.HC{:}CH.OH}_{\underbrace{2CH_2O}_{2CO+2H_2}}}
\end{array}$$

with the proviso that, in a sufficient supply of oxygen, the transition from the hydrocarbon to the *dihydroxy* stage is so rapid that no breaking down of the molecular structure occurs in passing through the *monohydroxy* stage. When, however, the supply of oxygen is reduced below the equimolecular proportion it is evident that the initial *monohydroxy* product cannot all be further oxidised to the dihydroxy stage; some of it must therefore decompose, yielding, usually, steam as one product. It will be immediately perceived that the above theory affords a complete explanation of the well-known fact that either ethylene or acetylene on explosion with its own volume of oxygen yields carbon monoxide and hydrogen, without any separation of carbon or steam formation, because in each case the principal intermediate product is formaldehyde. a substance which decomposes straight into carbon monoxide and hydrogen at high temperatures.

There are, moreover, two groups of facts relating to explosive combustion which, whilst they completely subvert the notion of a preferential combustion of carbon, harmonise very well with the new view of 'hydroxylation.' They are, briefly, as follows: (1) That whereas mixtures of olefines and oxygen corresponding to $C_nH_{2n}+\frac{n}{2}O_2$ behave on explosion like ethylene, inasmuch as they yield

mainly carbon monoxide and hydrogen without any separation of carbon, similar mixtures of paraffins and oxygen—namely, $C_nH_{2n+2}+\frac{n}{2}O_2$—yield carbon, oxides of carbon, methane, hydrogen, and steam all in considerable quantities. (2) That, even in the case of an olefine, if the proportion of oxygen be reduced below that indicated by the expression $C_nH_{2n}+\frac{n}{2}O_2$, both carbon and steam are prominently formed.

In his presidential address to this Section at the Leicester meeting in 1907, Smithells criticised the writer's interpretation of explosive combustion on the ground that '*the isolation of an intermediate product under one set of circumstances is in itself no proof that this product is transitorily formed when the reaction is proceeding under another set of circumstances.*' To this criticism it may be replied (1) that there is direct experimental proof of the formation of intermediate aldehydic products in hydrocarbon flames and explosions; (2) that notwithstanding the fact that the combustion of hydrocarbons has now been investigated over a range of temperature extending from that of incipient oxidation right up to the extreme conditions prevailing in detonation, no evidence has yet come to hand which warrants the assumption of any discontinuity in the immediate result of the initial encounter between hydrocarbon and oxygen molecules; and (3) that the theory of the intermediate formation of 'hydroxylated' or 'oxygenated' products furnishes a complete and sufficient explanation of the facts of hydrocarbon combustion as at present known, a requirement which no other alternative theory yet put forward is capable of satisfying. In this connection the writer is glad to find support in the recent presidential address of H. B. Dixon to the Chemical Society, where, speaking of the detonation of a mixture of equal volume of ethane and oxygen, he says: '*The ethane is not burnt wholly to carbon monoxide and hydrogen, but appears to form (as Professor Bone has shown at lower temperatures) acetaldehyde and steam, the acetaldehyde yielding methane and carbon monoxide.*' [1]

But to return to the consideration of facts: One of the most significant features of the writer's experiments has been the proof afforded of the relatively much greater affinity of hydrocarbons, as compared with that of either hydrogen or carbon monoxide, for oxygen at the high temperatures of flames. Thus when a mixture of acetylene and electrolytic gas corresponding to $C_2H_2+2H_2+O_2$ is exploded, there is absolutely no separation of carbon or formation of steam, and practically the same thing holds good in the case of a mixture of ethylene, hydrogen, and oxygen corresponding to $C_2H_4+H_2+O_2$. In each case the hydrocarbon is burnt to (ultimately) carbon monoxide and hydrogen, just as would be the case were no hydrogen originally present in the mixture. Recently the writer in an unpublished research on the division of oxygen between methane and hydrogen, in which mixtures corresponding to $CH_4+O_2+xH_2$ ($x=2$, 4, 6, or 8) have been exploded at high initial pressures, has proved that with $x=2$ upwards of 95 per cent. of the oxygen initially reacts with

[1] *Trans. Chem. Soc.*, 1910, 97, 665.

the hydrocarbon, and less than 5 per cent. of it goes to the hydrogen. Moreover, the proportion of the oxygen which goes to the hydrogen has been found to increase according to the second power of x, a circumstance which suggests that the combustion of hydrogen involves the trimolecular reaction $2H_2+O_2=2H_2O$, and not the initial formation of hydrogen peroxide, as some have supposed. A similar series of experiments with mixtures CH_4+O_2+xCO have proved that the affinity of carbon monoxide for oxygen is even less than that of hydrogen, and that the proportion of oxygen going to it increases as approximately the first power of x.

These observations have an important bearing on the chemistry of flames; hitherto hydrogen has been considered as one of the most combustible of gases, but in reality it is very much less so than hydrocarbons. Indeed, so overwhelmingly great is the affinity of a hydrocarbon for oxygen, as compared with the affinities of either hydrogen or carbon monoxide or with its own tendency to decompose, that the initial stage of its combustion probably takes precedence of all other chemical phenomena in flames. This is certainly true of the propagation of flame through a homogeneous explosive mixture of hydrocarbon and oxygen. In the special case of a stream of hydrocarbon burning in air, partial decomposition may possibly occur in the innermost regions of the flame, where the supply of oxygen is very limited, before actual combustion begins. But in general, whenever the hydrocarbon and oxygen meet at high temperatures, their mutual affinities will prove superior to any disruptive force which might otherwise break down the hydrocarbon. It is probably not so much the original hydrocarbon as its hydroxylated molecule which decomposes in ordinary flames. Be this, however, as it may, the experimental evidence does not warrant the view, so often encountered in scientific literature, that hydrocarbons are resolved into their elements prior to being burnt.[1]

SECTION VI.—*The Influence of Hot Surfaces upon Combustion.*

It is to the genius of Sir Humphry Davy that we owe the discovery of surface combustion. In his experiments on the ignition-points of various gases he had found, what is now a matter of common knowledge, that the constituents of a combustible mixture will combine with fair velocity at temperatures below the ignition-point. This led him to ask the question whether, seeing that the temperatures of flames far exceed those at which solids become incandescent, a metallic wire can be maintained at incandescence by the slow combination of two gases without actual flame. He therefore tried the effect of introducing a warm platinum wire into a jar containing a mixture of coal gas and air rendered non-explosive by an excess of the combustible constituents. The wire

[1] No attempt has been made in this report to discuss in any detail the experimental evidence on which the new theory of hydrocarbon combustion is based; the reader is referred to the series of papers published by the writer and his pupils (R. V. Wheeler, W. E. Stockings, G. W. Andrew, Julian Drugman, and H. L. Smith) in the *Trans. Chem. Soc.* (1902, 81, 535; 1903, 83, 1074; 1904, 85, 693, 1637; 1905, 87, 910, 1232; 1906, 89, 652, 660, 939, 1614).

immediately became red hot, and remained so until nearly the whole of the oxygen had disappeared. In subsequent experiments, Davy proved that hydrogen is far more susceptible to surface combustion than either ethylene or carbon monoxide; also, that the power of inducing surface combustion is by no means confined to the metals of the platinum group, which, however, exhibit it in an eminent degree.

In 1823 the subject was systematically investigated by Dulong and Thénard, and independently also by Döbereiner, who showed that all solids possess the power of accelerating combustion in varying degrees according to their specific characters and fineness of division. Two years later William Henry observed that when a platinum ball is immersed in a mixture of equal volumes of ethylene and electrolytic gas the hydrogen and oxygen alone combine, no combustion of the hydrocarbon occurring unless the original mixture contains a much larger proportion of oxygen. This important result was confirmed by Thomas Graham in 1829.

Several explanations of surface combustion were put forward by these early investigators. Davy himself suggested an electrochemical one. '*Supposing*,' he wrote, '*oxygen and hydrogen to be in the relation of negative and positive, it is necessary to effect their combination that their electricities should be brought into equilibrium or discharged. This is done by the electrical spark or flame, which offers a conducting medium for this purpose, or by raising them to a temperature in which they become themselves conductors. Now platinum, palladium, and iridium are bodies very slightly positive with respect to oxygen. . . . They offer to the gases the conducting medium necessary for carrying off and bringing into equilibrium their electricities without any intervening energy, and accumulate the heat produced by this equilibrium.*' Döbereiner, who discovered that freshly prepared platinum black absorbs oxygen from the air, and that in this 'oxygenated' condition it will cause steam to be formed on being plunged into a jar of oxygen, contended that the metal merely acts as a carrier of oxygen. On the other hand, Fusinieri (1825) maintained that it is the combustible gas (hydrogen) only which is affected by the surface, being condensed and rendered extraordinarily active by association with the surface.

The matter formed the subject of a celebrated controversy between Faraday and De la Rive in 1834-35. De la Rive strongly upheld the view that surface combustion essentially consists of a series of rapidly alternating oxidations and reductions of the catalysing material. Faraday, whilst not denying that finely divided platinum absorbs oxygen, argued with great force that true surface combustion involves an action quite distinct from that of an oxidised wire or foil upon a combustible gas. The function of the solid is, he contended, to condense both the oxygen and the combustible gas at the surface, thus producing a condition in the surface layer comparable to that of high pressure. After the year 1896, however, interest in the subject waned, and was not revived until quite recently.

It may here be remarked that heated surfaces have undoubtedly a marked influence in accelerating not only combustion but all chemical interchanges in gaseous systems. It is usually considered

that the action of the surfaces is merely an accelerating and not a directive one at any particular temperature, and although this may be generally true it is not necessarily or universally so. But in regard to combustion it may be assumed that, in general, the introduction of a hot surface will merely accelerate the process.

In the generation and applications of gaseous fuels the technologist has to deal not only with combustion, and the interaction of the products of incomplete combustion, but also with decomposition and dissociation phenomena, and contact with hot surfaces accelerates all alike. Thus the influence of hot solids—in the shape of furnace walls and the like—assumes an importance which can hardly be overestimated.

It will be generally agreed that the best means of elucidating the factors operative in surface combustion lies in determining the rates of combination of different gases with oxygen when the reacting mixtures are brought into contact with various solid surfaces at selected constant temperatures. This has been the line of attack usually adopted in recent investigations. But the method is only capable of yielding results of any value when the temperature selected is low enough to prevent the masking of the effects of surface combustion proper by changes in the main body of the gas, which is not in contact with the surface at any given instant.

In interpreting the results of such velocity measurements the following possible factors must be considered—namely, (1) the actual rate of combination at the surface, (2) the rates at which the reacting gases respectively diffuse inwards from the outside mixture on to the surface, (3) the rate at which the reaction product is removed from the surface, (4) the rates at which the reacting gases (or either of them) are rendered 'active' by the surface, supposing that the surface may act in some such manner, and (5) changes (if any) in the physical texture of the surface itself.

It is obvious that, since any system in which a gaseous mixture is combining exclusively at the surface of a heated solid must be regarded as heterogeneous, the velocity of reaction will not be governed by its 'order,' as would probably be the case with a homogeneous system. Nevertheless several recent investigators, notably Bodenstein in his earlier experiments upon the non-explosive combination of electrolytic gas in contact with the walls of a glazed porcelain vessel,[1] by overlooking this obvious consideration have largely invalidated their conclusions.

Of the factors above enumerated it is now generally agreed among competent observers that the actual rate of combination at the surface far exceeds either the rates of diffusion of the reacting gases on to the surface or the rates at which they are rendered 'active' by the surface. This being so, it follows that the amount of change observed in the system in unit time will not be governed by the actual rate of combination at the surface, but by one or other of the remaining factors, whichever happens to be the slowest in its operation.

Nernst, who has recently advanced a general theory of reactions in heterogeneous systems, based on measurements of the rates of solution

[1] *Zeit. phys. Chem.*, 1899, **29**, 665.

of salts in water, or of such substances as magnesia in acids, ignores (in the case of surface combustion) the possible 'activation' of the gases by the surface, and contends that the velocity of surface combustion is governed by diffusion factors only. Thus he has written:—

'*Da diese Reaktionen wohl ausschliesslich an der Grenzfläche des Katalysaten abspielen, so wird die Geschwindigkeit keineswegs durch den Mechanismus der betreffenden Reaktion, sondern wenn, was allerdings von vornherein nicht sicher ist, der Katalysaten während des Reaktionsverlaufes konstante Beschaffenheit behält und zugleich mit praktisch unendlicher Geschwindigkeit die betreffenden Substanzen an der Grenzfläche zur Reaktion bringt, auch hier lediglich durch die Diffusion der reagierenden Stoffe zum Katalysaten bedingt werden.*'[1]

Bodenstein,[2] in an entirely inconclusive series of experiments on the combination of hydrogen and oxygen in contact with platinum at the ordinary temperature, attempted to provide an experimental basis for the above theory, but it has been recently completely disproved by the researches of the writer and his pupils (R. V. Wheeler, G. W. Andrew, A. Forshaw, and H. Hartley), a first instalment only of which has so far been published.[3] The following is a brief *résumé* of the principal results of these researches:—

At an early stage of the research it became manifest that, in order to avoid errors inherent in a too restricted view of the phenomena, the action of a considerable variety of surfaces must be studied, including (1) such ordinarily non-oxidisable metals as gold, silver, and platinum, (2) oxidisable metals, such as copper and nickel, (3) easily reducible oxides, as well as (4) non-reducible oxides of both basic and acidic character. Although the investigation has revealed certain minor differences between the action of the various surfaces, the results as a whole leave no room for doubt but that the catalytic combustion depends primarily upon the condensation or absorption of one or other (and possibly both) of the reacting gases by the surface, whereby they are rendered 'active.' Any chemical explanation—such, for instance, as the supposition of a rapidly alternating series of oxidations and reductions of the catalysing surface—is inconsistent with the numerous velocity measurements made during the research. Equally certain is it that the rate of combustion is governed, not by diffusion factors, as Nernst has supposed, but by the rate of 'activation' of one of the reacting gases (and usually of the combustible gas) by the surface.

The catalysing power of a new surface at a given temperature usually increases up to a steady maximum when successive charges of the reacting gases, mixed in their combining ratios, are circulated over it; after the attainment of this steady condition, the rate of combination is always directly proportional to the pressure, provided that the gases are present in their combining ratios and the product of combustion is rapidly removed from the sphere of action. Where, however, one or other of the reacting gases is present in excess, the rate of combustion is in nearly all cases proportional to the partial presence of the combustible

[1] *Zeit. phys. Chem.*, 1904, 47, 55. [2] *Ibid.*, 1903, 46, 725.

[3] 'The Combination of Hydrogen and Oxygen in Contact with Hot Surfaces,' Bone and Wheeler, *Phil. Trans.*, 1906, A. 206, 1.

gas (*e.g.*, hydrogen or carbonic oxide), which thus becomes the ruling factor. The behaviour of copper oxide towards mixtures of hydrogen with excess of oxygen, and of nickel oxide towards mixtures of carbon monoxide with excess of oxygen, have so far proved exceptional in this respect, the observed rates in both cases being more nearly proportional to the partial pressure of the oxygen than to that of the combustible gas. In the case of copper oxide there is definite proof of the formation of a condensed film of 'active' oxygen at the surface, which actually burns up the hydrogen before it can reach the still more active oxygen chemically combined with the copper.

The catalysing powers of all the metallic and non-reducible oxide surfaces examined are highly stimulated by previous exposure to the combustible gas, which is undoubtedly rendered 'active' by association with the surface. This stimulus is usually very durable, but in most cases it is at once destroyed by a short exposure to oxygen. Although as a general rule oxygen has *per se* no stimulating effect on a catalysing surface, cases to the contrary have been encountered; but even in these exceptional instances the effect is neither so marked nor so durable as the corresponding effects always observed in respect of the combustible gas.

One notable feature with regard to the catalytic combustion of carbon monoxide over a fireclay surface is the fact that the rate of combustion of a mixture $2CO + O_2$ at 500° is about doubled by a thorough drying of the gases the 'reaction constant' increasing from about 0·09 to about 0·20. This remarkable result can hardly be explained on the supposition that, in the case of the undried mixture (saturated at 18°), steam acts merely as a diluent; it apparently exercises a specific retarding influence out of all proportion to its relative mass.

Of scarcely less interest are some recent results bearing upon the effects of a hot fireclay surface (at 500°) upon the relative rates of combustion of methane, hydrogen, and carbon monoxide. In the previous section attention was directed to the fact that in ordinary explosive combustion the affinities of methane and other hydrocarbons far exceed those either of hydrogen or of carbon monoxide for oxygen. In contact with a hot surface, however, the order is completely reversed, owing to an apparently selective action of the surface in rendering the combustible gases active. This circumstance is sufficient to invalidate the conclusions of certain earlier investigators, notably those of Landolt,[1] concerning the relative combustibilities of various gases, owing to their having sucked off the products of partial combustion from the inner regions of coal-gas flames through platinum tubes and the like. It may be taken for granted that the introduction of a hot solid into a mixture of burning gases is in itself sufficient to upset the regular conditions of explosive combustion.

The conclusions drawn by Bone and Wheeler[2] as to the catalytic combustion of hydrogen derive collateral support from the recent researches of Sabatier and Senderens on the remarkable powers of many metallic surfaces (and especially nickel) of rendering this gas 'active'

[1] *Über die chemischen Vorgänge in der Flamme des Leuchtgas.* Habilitationsschrift. Breslau, 1856.

[2] *Loc. cit.*

at comparatively low temperatures. In illustration of their results may be quoted the following remarkable instances of direct 'hydrogenations' effected by merely passing a mixture of the substance in question with hydrogen over finely divided and freshly reduced nickel. In this way olefinic hydrocarbons are convertible into the corresponding paraffins at 160°; benzene yields cyclo-hexane; nitro-benzene may be reduced to aniline; whilst nitro-methane is convertible into methylamine at 150° to 180°, and into methane and ammonia at 350°. Finally, a mixture of carbon monoxide (1 vol.) and hydrogen (3 vols.) may be completely transformed into methane and steam at 250°.

In the present imperfect state of our knowledge any suggestion which may be put forward as to the action of hot surfaces in rendering such gases as hydrogen or carbon monoxide 'active' must be considered as quite tentative. Several facts, however, point to a possible connection between surface combustion and the emission of charged particles by hot solids. In 1903 H. A. Wilson [1] discovered that hydrogen has an enormous influence upon the negative leakage from a clean platinum wire at high temperatures; thus at 135°, for a given potential difference, the leakage in hydrogen at 0·014 mm. pressure was found to be no less than 25,000 times greater than in air; it was also proportional to the pressure and depended upon the hydrogen actually occluded by the metal. These observations have since been confirmed by O. W. Richardson [2]—who, however, finds that the leakage consists of two parts, one proportional to the pressure (due to ionisation by collisions) and the other independent of it; he takes the view that hydrogen does not act *per se*, but only indirectly by producing some change in the surface of the metal.

Sir J. J. Thomson has found that the rate of emission of negative corpuscles by alkali metals at ordinary temperatures is greatly increased whilst they are absorbing hydrogen,[3] and F. Horton has proved that the negative leakage from hot lime is much greater in hydrogen than in air.[4]

With regard to the catalytic combustion of hydrogen in contact with metallic surfaces P. J. Kirkby, in experimenting upon the effects of electrically heating a platinum wire to *circa* 275° in electrolytic gas at pressures under 40 mm., concluded that it is '*probably connected with the corpuscular discharge which is known to be emitted by platinum.*' [5] Finally, it has recently been proved in the writer's laboratory that gold gauze immediately acquires a negative charge on its inducing the surface combustion of either hydrogen or of carbon monoxide. All these facts point to the necessity of a systematic investigation of the electrical condition of heated surfaces during catalytic combustions as a preliminary to a better understanding of the phenomenon.

[1] *Phil. Trans.*, A. 202, 243.
[2] *Ibid.*, 1908, A. 207, 1.
[3] *Phil. Mag.*, 1905, 6th series, 10, 584.
[4] *Phil. Trans.*, 1908, A. 207, 149.
[5] *Phil. Mag.*, 1905, 6th series, 10, 467.

Discussion.[1]

Sir J. J. THOMSON called attention to the fact that combustion was concerned not only with atoms and molecules but also with electrons —*i.e.*, bodies of much smaller dimensions and moving with very high velocities. These may precede the explosion-wave and prepare the way for it by ionising the gas. But the motion of the ions can be stopped at once by means of a transverse magnetic field, in which they curl up and are caused to revolve in small circles. It would be of very great interest if Professor Dixon's experiments on the photography of the explosion-wave could be repeated under such conditions as to determine whether the form of the wave could be modified by such a magnetic field. The positive and negative electrons were of very different dimensions, and when first projected travelled with widely different velocities; but in an ordinary gas these velocities soon become almost identical. It had, however, been shown by the work of Townsend at Oxford and of certain workers on the Continent that in carefully-dried gases the velocity of the negative electrons might be 100 times as great as the velocity of the positive electrons. The amount of moisture required to reduce this velocity to its ordinary lower value was exceedingly small comparable with that required to initiate chemical change. It was not unlikely that the two phenomena were very closely related.

In reference to the influence of hot surfaces in promoting combustion to which Professor Bone had drawn attention, it was not improbable that the emission of charged particles from the surface was a factor of primary importance. Hot lime gave out an enormous stream of negative electrons travelling with a high velocity, whilst hot metals emitted an excess of positive electrons, as indeed Professor Bone had found by the development of a negative charge on the silver foil which he had used as a contact surface. These electrons might produce very important effects by uniting (perhaps selectively) with moisture, with the oxygen, and with the inflammable constituent of the gaseous mixture. The mode of action of the oxides was specially worthy of investigation. Chemists recognised two stages of oxidation in baryta, and perhaps in lime. It might be that the problem of the source of the energy of the torrent of electrons might be found in the oxidation and reduction of the contact substance. He suggested that the action of surfaces might ultimately be found to depend on the fact that they formed a support for layers of electrified gas in which chemical changes proceeded with high velocity.

Sir OLIVER LODGE strongly supported the proposal that experiments should be carried out on the velocity of propagation of explosion-waves in a magnetic field. The high velocity of the detonation-wave seemed to point to the initiation of some new type of chemical change, such as a burning of carbon following the burning of sulphur in the combustion of carbon bisulphide, or the initiation of a change involving the collision of three instead of two molecules. The velocity of sound which had

[1] Compiled by the Sectional Secretaries.

been referred to as a factor in connection with the explosion-wave was not a constant quantity. A bullet, for instance, cannot really travel with a velocity greater than that of sound; if it did the air would be shattered as if by an explosion and the bullet stopped. This result was in practice prevented by the compression and consequent heating of the air in front of the bullet, whereby the velocity of sound was momentarily increased immediately in front of the bullet to perhaps three times its ordinary value in accordance with the equation $V^2 = kRT$. That very great heating could thus actually occur was shown by the fact that the compression was made use of in the Diesel engine to produce ignition. The rate of explosion must depend a good deal on the amount of exposed surface. Whilst hot surfaces promoted combustion, cool surfaces unfortunately had an opposite effect. This was responsible for the production of vast quantities of soot and smoke, especially in firing steam boilers, and also gave rise to trouble in heating and annealing armour-plates. If a surface could be discovered which would promote combustion even at lower temperatures the discovery would be of very great value. The escape of an electric charge from a contact surface during combustion might very well be purely mechanical, the positively-charged adhering layer being literally scraped away by the force of the flame.

Professor H. B. DIXON, referring to his recent work, said that Nernst had suggested that a gas fired by compression would be heated uniformly and would therefore detonate as a whole. This was not found to be the case; the gas actually fires in a particular layer, though the explosion begins rather indefinitely, and no well-defined sound-waves are propagated from the point of ignition. The explosion of hydrogen and chlorine by light was of special interest, as it did not occur in the well-dried gas. In the moist gas there was an interval of time before explosion took place, similar to the 'pre-flame period' in gases fired by adiabatic compression. But when once the wave was started, whether by a spark or a flame or by light, it proceeded independently of moisture, and indeed was actually most rapid in the dry gas. The explosion was then propagated by molecular collision, and on account of its high velocity, probably by collisions between pairs of molecules only—a point on which Sir J. Larmor had laid special stress in his Wilde lecture. In the explosion of hydrogen and oxygen, as in that of hydrogen and chlorine, the action started by a spark was propagated as well in the dried as in the undried gas. So far experiments on the influence of an electric field had given negative results, and the action of Röntgen rays on a mixture of hydrogen and chlorine did not render it more sensitive to light.

Supporting the suggestion of Sir J. J. Thomson, he thought it not unlikely that an invisible compression-wave might travel just in front of the visible flame, the particles being thereby raised to a high temperature. The brightness of the flame might well be due to the fact that the gas was already very hot before combustion occurred. He proposed to repeat the experiments of exploding gases in a strong magnetic field and photographing the flame.

Professor SMITHELLS hoped that the report would be carefully read

by the members of Section A. The matter had now been carried to a point at which the co-operation of physicists was absolutely essential for further advance. Chemists had been compelled to acknowledge their limitations by using meaningless words such as 'catalysis' and 'contact-action' to conceal their ignorance. The real meaning of these words might be found if the co-operation of physicists could be secured.

Professor ARMSTRONG regretted the absence of the engineers, who were discussing, at a separate gathering, a problem which appeared, from the printed report of their Committee, to be essentially physical in its main features and almost identical in character with that which Sections A and B were now discussing. He dwelt on the need of an understanding being arrived at by chemists and physicists as to the nature of chemical change—the phenomena could not well be interpreted either from a purely chemical or from a purely physical point of view; at present they could not help one another because they did not understand one another; the two parties did not seem able to arrive at a common understanding, nor would they until each could fully appreciate the point of view taken by the other. Such meetings as that they were holding were becoming of the utmost consequence to the progress of science in these days of extreme specialisation. He had heard with pleasure that, at last, Professor Dixon was prepared to admit that the presence of moisture was at least necessary in starting the wave of explosion in a mixture of hydrogen and chlorine; the speaker thought he would ultimately be obliged to admit that it was necessary throughout.

If moisture be present initially and be instrumental in conditioning the explosive wave, it must remain in the wave front and be operative throughout the explosion, even supposing the gas in which the wave is advancing to be dry; an excess of water, however, might well act detrimentally by promoting reversals.

It appeared to him to be now established that action could not take place unless a conducting system were formed; this was equally true of ordinary cases of chemical change and of the passage of an electric discharge through gases. One member of the system must be an electrolyte. (Sir J. J. Thomson here interposed the remark: 'What is an electrolyte?' and appeared to imply that any substance would behave as an electrolyte if only a sufficient electromotive force were applied.) Professor Armstrong insisted on the need of distinguishing between electrolytes and non-electrolytes; he then dwelt on the very great importance from this point of view of Sir James Dewar's observation that the atmosphere of a bulb containing helium could be so far purified by means of charcoal cooled by liquid hydrogen that it was impossible to pass an electrical discharge across the bulb even when a high potential was used, although the vanes of a Crookes' radiometer mounted within it rotated merrily when a heat source was presented to the bulb. He insisted on this observation as proof that conductivity was conditioned not by the mere presence of gas, but of a gas in association with the necessary impurity (conducting impurity) to render possible the formation of conducting systems within the tube.

[The argument is probably one of great importance in connection with the assumption that electrons exist as distinct entities. The

substances which are supposed to give off electrons when heated are all substances that are more or less easily dissociated and the experiments made with such substances have not been carried out with the scrupulous care to remove 'impurities' which the observations made by Brereton Baker and Dewar have shown to be necessary. There is nothing at present to prove that 'electrons' are given off otherwise than in cases in which an ordinary discharge will pass. Moreover, the argument on which the determination of the size of negative electrons is based is in no sense one which serves to place their existence beyond question. It is now admitted by prominent physicists that molecules can carry charges—those of helium, for example—so that it is not even necessary to assume the existence of dissociated charged ions as carriers of electricity. The admission is of some importance, as, in the early days of the discussion on electrolysis, the contention that molecules and aggregates of molecules might act as carriers was scorned. Compare 'The Conditions Determinative of Chemical Change and of Electrical Conduction in Gases and on the Phenomenon of Luminosity.'[1] H. E. A.]

Professor Bone, writing in reply, hoped that this discussion would lead to a more active co-operation between physicists and chemists in the further investigation and interpretation of gaseous combustion. If it be admitted (1) that the forces holding the atoms of a molecule together are electrical in character, and (2) that the unit of electricity is corpuscular and capable of independent movement outside the boundary of the chemical molecule, it seems probable that such corpuscular electric units ('electrons') play some part in gaseous combustion. The utility of the 'electron' theory to chemists, however, will largely depend upon its ability to interpret some of the more obscure factors in combustion dealt with in the report.

With regard to the subject of 'surface combustion,' recent experiments carried out by Mr. H. Hartley and himself (the details of which would be published shortly) had proved that certain ordinarily non-oxidisable metals (silver, gold, &c.) become *negatively* charged when heated at 200° to 400° in either hydrogen or carbon monoxide, and *positively* charged on being similarly heated in oxygen. These surfaces also become *negatively* charged during the catalytic combustion either of hydrogen or of carbon monoxide, although there is so far no evidence that the main body of the gas outside of the catalysing surface becomes 'ionised' to any appreciable extent.

If the + or − charging of the surface really implies the escape therefrom of − or + 'electrons' respectively with velocities insufficient either to ionise the gas outside, or even to allow of their travelling far from the surface (so that they would be likely to remain within range of the attraction of the layer of opposite sign on the surface), it seems at least conceivable that such slowly moving electrons may attach themselves to, or condense around them, the molecules of combustible gas or of oxygen, which, thus charged, would be attracted to the surface. Some such view, if admissible from the standpoint of the

[1] *Roy. Soc. Proc.*, 1902, 72, 99.

physicists, would seem capable of explaining certain of the phenomena of surface combustion; as, for example, the quite abnormal retarding influence of moisture referred to in the report. But before any such idea can be confidently adopted as a working hypothesis by chemists, it will be necessary for physicists to define more clearly than they have done hitherto the function and significance of the supposed 'electrons' in chemical interchanges. From the chemists' standpoint, a clear statement of the physicists' views in relation to these matters is urgently needed, and, if forthcoming, would considerably enlarge the field of immediate experimental inquiry.

TRANSACTIONS OF THE SECTIONS.

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Section A.—MATHEMATICAL AND PHYSICAL SCIENCE.

President of the Section.—Professor E. W. Hobson, D.Sc., F.R.S.

THURSDAY, SEPTEMBER 1.

The President delivered the following Address:—

Since the last meeting of our Association one of the most illustrious of the British workers in science during the nineteenth century has been removed from us by the death of Sir William Huggins. In the middle of the last century Sir William Huggins commenced that pioneer work of examination of the spectra of the stars which has ensured for him enduring fame in connection with the foundation of the science of Astrophysics. The exigencies of his work of analysis of the stellar spectra led him to undertake a minute examination of the spectra of the elements with a view to the determination of as many lines as possible. To the spectroscope he later added the photographic film as an instrument of research in his studies of the heavenly bodies. In 1864 Sir William Huggins made the important observation that many of the nebulæ have spectra which consist of bright lines; and two years later he observed, in the case of a new star, both bright and dark lines in the same spectrum. In 1868 his penetrating and alert mind made him the first to perceive that the Doppler principle could be applied to the determination of the velocities of stars in the line of sight, and he at once set about the application of the method. His life-work, in a domain of absorbing interest, was rewarded by a rich harvest of discovery, obtained as the result of most patient and minute investigations. The 'Atlas of Representative Stellar Spectra,' published in the names of himself and Lady Huggins, remains as a monumental record of their joint labours.

The names of the great departments of science, Mathematics, Physics, Astronomy, Meteorology, which are associated with Section A, are a sufficient indication of the vast range of investigation which comes under the purview of our Section. An opinion has been strongly expressed in some quarters that the time has come for the erection of a separate Section for Astronomy and Meteorology, in order that fuller opportunities may be afforded than hitherto for the discussion of matters of special interest to those devoted to these departments of Science. I do not share this view. I believe that, whilst the customary division into sub-sections gives reasonable facilities for the treatment of questions interesting solely to specialists in the various branches with which our Section is concerned, a policy of disruption would be injurious to the wider interests of science. The close association of the older Astronomy with Mathematics, and of the newer Astronomy with Physics, form strong presumptions against the change that has been suggested. Meteorology, so far as it goes beyond the purely empirical region, is, and must always remain, a branch of Physics. No doubt, the more technical problems which arise in connection with these subjects, though of

great importance to specialists, are often of little or no interest to workers in cognate departments. It appears to me, however, that it is unwise, in view of the general objects of the British Association, to give too much prominence in the meetings to the more technical aspects of the various departments of science. Ample opportunities for the full discussion of all the detailed problems, the solution of which forms a great and necessary part of the work of those who are advancing science in its various branches, are afforded by the special Societies which make those branches their exclusive concern. The British Association will, in my view, be performing its functions most efficiently if it gives much prominence to those aspects of each branch of science which are of interest to a public at least in some degree larger than the circle of specialists concerned with the particular branch. To afford an opportunity to workers in any one department of obtaining some knowledge of what is going on in other departments, to stimulate by means of personal intercourse with workers on other lines the sense of solidarity of men of science, to do something to counteract that tendency to narrowness of view which is a danger arising from increasing specialisation, are functions the due performance of which may do much to further that supreme object, the advancement of science, for which the British Association exists.

I propose to address to you a few remarks, necessarily fragmentary and incomplete, upon the scope and tendencies of modern Mathematics. Not to transgress against the canon I have laid down, I shall endeavour to make my treatment of the subject as little technical as possible.

Probably no other department of knowledge plays a larger part outside its own narrower domain than Mathematics. Some of its more elementary conceptions and methods have become part of the common heritage of our civilisation, interwoven in the everyday life of the people. Perhaps the greatest labour-saving invention that the world has seen belongs to the formal side of Mathematics; I allude to our system of numerical notation. This system which, when scrutinised, affords the simplest illustration of the importance of Mathematical form, has become so much an indispensable part of our mental furniture that some effort is required to realise that an apparently so obvious idea embodies a great invention; one to which the Greeks, with their unsurpassed capacity for abstract thinking, never attained. An attempt to do a multiplication sum in Roman numerals is perhaps the readiest road to an appreciation of the advantages of this great invention. In a large group of sciences, the formal element, the common language, so to speak, is supplied by Mathematics; the range of the application of mathematical methods and symbolism is ever increasing. Without taking too literally the celebrated dictum of the great philosopher Kant, that the amount of real science to be found in any special subject is the amount of Mathematics contained therein, it must be admitted that each branch of science which is concerned with natural phenomena, when it has reached a certain stage of development, becomes accessible to, and has need of, mathematical methods and language; this stage has, for example, been reached in our time by parts of the science of Chemistry. Even Biology and Economics have begun to require mathematical methods, at least on their statistical side. As a science emerges from the stages in which it consists solely of more or less systematised descriptions of the phenomena with which it is concerned in their more superficial aspect; when the intensive magnitudes discerned in the phenomena become representable as extensive magnitudes, then is the beginning of the application of mathematical modes of thought; at a still later stage, when the phenomena become accessible to dynamical treatment, Mathematics is applicable to the subject to a still greater extent.

Mathematics shares with the closely allied subject of Astronomy the honour of being the oldest of the sciences. When we consider that it embodies, in an abstract form, some of the more obvious, and yet fundamental, aspects of our experience of the external world, this is not altogether surprising. The comparatively high degree of development which, as recent historical discoveries have disclosed, it had attained amongst the Babylonians more than five thousand years B.C., may well astonish us. These times must have been preceded by still earlier ages in which the mental evolution of man led him to the use of the tally, and of simple modes of measurement, long before the notions of number and of magnitude appeared in an explicit form.

I have said that Mathematics is the oldest of the sciences; a glance at its more recent history will show that it has the energy of perpetual youth. The output of contributions to the advance of the science during the last century and more has been so enormous that it is difficult to say whether pride in the greatness of achievement in his subject, or despair at his inability to cope with the multiplicity of its detailed developments, should be the dominant feeling of the mathematician. Few people outside the small circle of mathematical specialists have any idea of the vast growth of mathematical literature. The Royal Society Catalogue contains a list of nearly thirty-nine thousand papers on subjects of Pure Mathematics alone, which have appeared in seven hundred serials during the nineteenth century. This represents only a portion of the total output; the very large number of treatises, dissertations, and monographs published during the century being omitted. During the first decade of the twentieth century this activity has proceeded at an accelerated rate. Mathematical contributions to Mechanics, Physics, and Astronomy would greatly swell the total. A notion of the range of the literature relating not only to Pure Mathematics but also to all branches of science to which mathematical methods have been applied will be best obtained by an examination of that monumental work, the 'Encyclopädie der mathematischen Wissenschaften'—when it is completed.

The concepts of the pure mathematician, no less than those of the physicist, had their origin in physical experience analysed and clarified by the reflective activities of the human mind; but the two sets of concepts stand on different planes in regard to the degree of abstraction which is necessary in their formation. Those of the mathematician are more remote from actual unanalysed percepts than are those of the physicist, having undergone in their formation a more complete idealisation and removal of elements inessential in regard to the purposes for which they are constructed. This difference in the planes of thought frequently gives rise to a certain misunderstanding between the mathematician and the physicist, due in the case of either to an inadequate appreciation of the point of view of the other. On the one hand it is frequently and truly said of particular mathematicians that they are lacking in the physical instinct; and on the other hand a certain lack of sympathy is frequently manifested on the part of physicists for the aims and ideals of the mathematician. The habits of mind and the ideals of the mathematician and of the physicist cannot be of an identical character. The concepts of the mathematician necessarily lack, in their pure form, just that element of concreteness which is an essential condition of the success of the physicist, but which to the mathematician would often only obscure those aspects of things which it is his province to study. The abstract mathematical standard of exactitude is one of which the physicist can make no direct use. The calculations in Mathematics are directed towards ideal precision, those in Physics consist of approximations within assigned limits of error. The physicist can, for example, make no direct use of such an object as an irrational number; in any given case a properly chosen rational number approximating to the irrational one is sufficient for his purpose. Such a notion as continuity, as it occurs in Mathematics, is, in its purity, unknown to the physicist, who can make use only of sensible continuity. The physical counterpart of mathematical discontinuity is very rapid change through a thin layer of transition, or during a very short time. Much of the skill of the true mathematical physicist and of the mathematical astronomer consists in the power of adapting methods and results carried out on an exact mathematical basis to obtain approximations sufficient for the purposes of physical measurement. It might perhaps be thought that a scheme of Mathematics on a frankly approximative basis would be sufficient for all the practical purposes of application in Physics, Engineering Science, and Astronomy; and no doubt it would be possible to develop, to some extent at least, a species of Mathematics on these lines. Such a system would, however, involve an intolerable awkwardness and prolixity in the statement of results, especially in view of the fact that the degrees of approximation necessary for various purposes are very different, and thus that unassigned grades of approximation would have to be provided for. Moreover the mathematician working on these lines would be cut off from his chief sources of inspiration, the ideals of exactitude and logical rigour, as well as from one of his most indispensable guides to discovery, symmetry and permanence of mathematical form. The

history of the actual movements of mathematical thought through the centuries shows that these ideals are the very life-blood of the science, and warrants the conclusion that a constant striving towards their attainment is an absolutely essential condition of vigorous growth. These ideals have their roots in irresistible impulses and deep-seated needs of the human mind, manifested in its efforts to introduce intelligibility into certain great domains of the world of thought.

There exists a widespread impression amongst physicists, engineers, and other men of science that the effect of recent developments of Pure Mathematics, by making it more abstract than formerly, has been to remove it further from the order of ideas of those who are primarily concerned with the physical world. The prejudice that Pure Mathematics has its sole *raison d'être* in its function of providing useful tools for application in the physical sciences, a prejudice which did much to retard the due development of Pure Mathematics in this country during the nineteenth century, is by no means extinct. It is not infrequently said that the present devotion of many mathematicians to the interminable discussion of purely abstract questions relating to modern developments of the notions of number and function, and to theories of algebraic form, serves only the purpose of deflecting them from their proper work into paths which lead nowhere. It is considered that mathematicians are apt to occupy themselves too exclusively with ideas too remote from the physical order in which Mathematics had its origin and in which it should still find its proper applications. A direct answer to the question *cui bono?* when it is raised in respect of a department of study such as Pure Mathematics, seldom carries conviction, in default of a standard of values common to those who ask and to those who answer the question. To appreciate the importance of a sphere of mental activity different from our own always requires some effort of the sympathetic imagination, some recognition of the fact that the absolute value of interests and ideals of a particular class may be much greater than the value which our own mentality inclines us to attach to them. If a defence is needed of the expenditure of time and energy on the abstract problems of Pure Mathematics, that defence must be of a cumulative character. The fact that abstract mathematical thinking is one of the normal forms of activity of the human mind, a fact which the general history of thought fully establishes, will appeal to some minds as a ground of decisive weight. A great department of thought must have its own inner life, however transcendent may be the importance of its relations to the outside. No department of science, least of all one requiring so high a degree of mental concentration as Mathematics, can be developed entirely, or even mainly, with a view to applications outside its own range. The increased complexity and specialisation of all branches of knowledge makes it true in the present, however it may have been in former times, that important advances in such a department as Mathematics can be expected only from men who are interested in the subject for its own sake, and who, whilst keeping an open mind for suggestions from outside, allow their thought to range freely in those lines of advance which are indicated by the present state of their subject, untrammelled by any preoccupation as to applications to other departments of science. Even with a view to applications, if Mathematics is to be adequately equipped for the purpose of coping with the intricate problems which will be presented to it in the future by Physics, Chemistry, and other branches of physical science, many of these problems probably of a character which we cannot at present forecast, it is essential that Mathematics should be allowed to develop itself freely on its own lines. Even if much of our present mathematical theorising turns out to be useless for external purposes, it is wiser, for a well-known reason, to allow the wheat and the tares to grow together. It would be easy to establish in detail that many of the applications which have been actually made of Mathematics were wholly unforeseen by those who first developed the methods and ideas on which they rest. Recently, the more refined mathematical methods which have been applied to gravitational Astronomy by Delaunay, G. W. Hill, Poincaré, E. W. Brown, and others, have thrown much light on questions relating to the solar system, and have much increased the accuracy of our knowledge of the motions of the moon and the planets. Who knows what weapons forged by the theories of functions, of differential equations, or of groups, may be required when the time comes for such an empirical law as Mendeléeff's periodic law of

the elements to receive its dynamical explanation by means of an analysis of the detailed possibilities of relatively stable types of motion, the general schematic character of which will have been indicated by the physicist? It is undoubtedly true that the cleft between Pure Mathematics and Physical Science is at the present time wider than formerly. That is, however, a result of the natural development, on their own lines, of both subjects. In the classical period of the eighteenth century, the time of Lagrange and Laplace, the nature of the physical investigations, consisting largely of the detailed working out of problems of gravitational Astronomy in accordance with Newton's law, was such that the passage was easy from the concrete problems to the corresponding abstract mathematical ones. Later on, mathematical physicists were much occupied with problems which lent themselves readily to treatment by means of continuous analysis. In our own time the effect of recent developments of Physics has been to present problems of molecular and sub-molecular Mechanics to which continuous analysis is not at least directly applicable, and can only be made applicable by a process of averaging the effects of great swarms of discrete entities. The speculative and incomplete character of our conceptions of the structure of the objects of investigation has made the applications of Dynamics to their detailed elucidation tentative and partial. The generalised dynamical scheme developed by Lagrange and Hamilton, with its power of dealing with systems, the detailed structure of which is partially unknown, has however proved a powerful weapon of attack, and affords a striking instance of the deep-rooted significance of mathematical form. The wonderful and perhaps unprecedentedly rapid discoveries in Physics which have been made in the last two decades have given rise to many questions which are as yet hardly sufficiently definite in form to be ripe for mathematical treatment; a necessary condition of which treatment consists in a certain kind of precision in the data of the problems to be solved.

The difficulty of obtaining an adequate notion of the general scope and aims of Mathematics, or even of special branches of it, is perhaps greater than in the case of any other science. Many persons, even such as have made a serious and prolonged study of the subject, feel the difficulty of seeing the wood for trees. The severe demands made upon students by the labour of acquiring a difficult technique largely accounts for this; but teachers might do much to facilitate the attainment of a wider outlook by directing the attention of their students to the more general and less technical aspects of the various parts of the subject, and especially by the introduction into the courses of instruction of more of the historical element than has hitherto been usual.

All attempts to characterise the domain of Mathematics by means of a formal definition which shall not only be complete, but which shall also rigidly mark off that domain from the adjacent provinces of Formal Logic on the one side and of Physical Science on the other side, are almost certain to meet with but doubtful success; such success as they may attain will probably be only transient, in view of the power which the science has always shown of constantly extending its borders in unforeseen directions. Such definitions, many of which have been advanced, are apt to err by excess or defect, and often contain distinct traces of the personal predilections of those who formulate them. There was a time when it would have been a tolerably sufficient description of Pure Mathematics to say that its subject-matter consisted of magnitude and geometrical form. Such a description of it would be wholly inadequate at the present day. Some of the most important branches of modern Mathematics, such as the theory of groups, and Universal Algebra, are concerned, in their abstract forms, neither with magnitude nor with number, nor with geometrical form. That great modern development, Projective Geometry, has been so formulated as to be independent of all metric considerations. Indeed the tendency of mathematicians under the influence of the movement known as the Arithmetisation of Analysis, a movement which has become a dominant one in the last few decades, is to banish altogether the notion of measurable quantity as a conception necessary to Pure Mathematics; Number, in the extended meaning it has attained, taking its place. Measurement is regarded as one of the applications, but as no part of the basis, of mathematical analysis. Perhaps the least inadequate description of the general scope of modern Pure Mathematics—I will not call it a definition—would be to say that it deals with *form*, in a very general sense of

the term; this would include algebraic form, geometrical form, functional relationship, the relations of order in any ordered set of entities such as numbers. and the analysis of the peculiarities of form of groups of operations. A strong tendency is manifested in many of the recent definitions to break down the line of demarcation which was formerly supposed to separate Mathematics from formal logic; the rise and development of symbolic logic has no doubt emphasised this tendency. Thus Mathematics has been described by the eminent American mathematician and logician B. Pierce as 'the Science which draws necessary conclusions,' a pretty complete identification of Mathematics with logical procedure in general. A definition which appears to identify all Mathematics with the Mengenlehre, or Theory of Aggregates, has been given by E. Papperitz: 'The subject-matter of Pure Mathematics consists of the relations that can be established between any objects of thought when we regard those objects as contained in an ordered manifold; the law of order of this manifold must be subject to our choice.' The form of definition which illustrates most strikingly the tendencies of the modern school of logistic is one given by Mr. Bertrand Russell. I reproduce it here, in order to show how wide is the chasm between the modes of expression of adherents of this school and those of mathematicians under the influence of the ordinary traditions of the science. Mr. Russell writes:[1] 'Pure Mathematics is the class of all propositions of the form "p implies q," where p and q are propositions containing one or more variables, the same in the two propositions, and neither p nor q contains any constants except logical constants. And logical constants are all notions definable in terms of the following: Implication, the relation of a term to a class of which it is a member the notion of *such that*, the notion of relation, and such further notions as may be involved in the general notion of propositions of the above form. In addition to these, Mathematics *uses* a notion which is not a constituent of the propositions which it considers—namely, the notion of truth.'

The belief is very general amongst instructed persons that the truths of Mathematics have absolute certainty, or at least that there appertains to them the highest degree of certainty of which the human mind is capable. It is thought that a valid mathematical theorem is necessarily of such a character as to compel belief in any mind capable of following the steps of the demonstration. Any considerations tending to weaken this belief would be disconcerting and would cause some degree of astonishment. At the risk of this, I must here mention two facts which are of considerable importance as regards an estimation of the precise character of mathematical knowledge. In the first place, it is a fact that frequently, and at various times, differences of opinion have existed among mathematicians, giving rise to controversies as to the validity of whole lines of reasoning and affecting the results of such reasoning; a considerable amount of difference of opinion of this character exists among mathematicians at the present time. In the second place, the accepted standard of rigour, that is, the standard of what is deemed necessary to constitute a valid demonstration, has undergone change in the course of time. Much of the reasoning which was formerly regarded as satisfactory and irrefutable is now regarded as insufficient to establish the results which it was employed to demonstrate. It has even been shown that results which were once supposed to have been fully established by demonstrations are, in point of fact, affected with error. I propose here to explain in general terms how these phenomena are possible.

In every subject of study, if one probes deep enough, there are found to be points in which that subject comes in contact with general philosophy, and where differences of philosophical view will have a greater or less influence on the attitude of the mind towards the principles of the particular subject. This is not surprising when we reflect that there is but one universe of thought, that no department of knowledge can be absolutely isolated, and that metaphysical and psychological implications are a necessary element in all the activities of the mind. A particular department, such as Mathematics, is compelled to set up a more or less artificial frontier, which marks it off from general philosophy. This frontier consists of a set of regulative ideas in the form of indefinables and axioms, partly ontological assumptions, and partly postulations of a logical

[1] *Principles of Mathematics*, p. 1.

character. To go behind these, to attempt to analyse their nature and origin, and to justify their validity, is to go outside the special department and to touch on the domains of the metaphysician and the psychologist. Whether they are regarded as possessing apodictic certainty or as purely hypothetical in character, these ideas represent the data or premisses of the science, and the whole of its edifice is dependent upon them. They serve as the foundation on which all is built, as well as the frontier on the side of philosophy and psychology. A set of data ideally perfect in respect of precision and permanence is unattainable—or at least has not yet been attained; and the adjustment of frontiers is one of the most frequent causes of strife. As a matter of fact, variations of opinion have at various times arisen within the ranks of the mathematicians as to the nature, scope, and proper formulation of the principles which form the foundations of the science, and the views of mathematicians in this regard have always necessarily been largely affected by the conscious or unconscious attitude of particular minds towards questions of general philosophy. It is in this region, I think, that the source is to be found of those remarkable differences of opinion amongst mathematicians which have come into prominence at various times, and have given rise to much controversy as to fundamentals. Since the time of Newton and Leibnitz there has been almost unceasing discussion as to the proper foundations for the so-called infinitesimal calculus. More recently, questions relating to the foundations of geometry and rational mechanics have much occupied the attention of mathematicians. The very great change which has taken place during the last half-century in the dominant view of the foundations of mathematical analysis—a change which has exercised a great influence extending through the whole detailed treatment of that subject—although critical in its origin, has been constructive in its results. The Mengenlehre, or theory of aggregates, had its origin in the critical study of the foundations of analysis, but has already become a great constructive scheme, is indispensable as a method in the investigations of analysis, provides the language requisite for the statement in precise form of analytical theorems of a general character, and, moreover, has already found important applications in geometry. In connection with the Mengenlehre there has arisen a controversy amongst mathematicians which is at the present time far from having reached a decisive issue. The exact point at issue is one which may be described as a matter of mathematical ontology; it turns upon the question of what constitutes a valid definition of a mathematical object. The school known as mathematical 'idealists' admit, as valid objects of mathematical discussion, entities which the rival 'empiricist' school regard as non-existent for mathematical thought, because insufficiently defined. It is clear that the idealist may build whole superstructures on a foundation which the empiricist regards as made of sand, and this is what has actually happened in some of the recent developments of what has come to be known as Cantorism. The difference of view of these rival schools, depending as it does on deep-seated differences of philosophical outlook, is thought by some to be essentially irreconcilable. This controversy was due to the fact that certain processes of reasoning, of very considerable plausibility, which had been employed by G. Cantor, the founder of the Mengenlehre, had led to results which contained flat contradictions. The efforts made to remove these contradictions, and to trace their source, led to the discussion, disclosing much difference of opinion, of the proper definitions and principles on which the subject should be based.

The proposition $7+5=12$, taken as typical of the propositions expressing the results of the elementary operations of arithmetic, has since the time of Kant given rise to very voluminous discussion amongst philosophers, in relation to the precise meaning and implication of the operation and the terms. It will, however, be maintained, probably by the majority of mankind, that the theorem retains its validity as stating a practically certain and useful fact, whatever view philosophers may choose to take of its precise nature—as, for example, whether it represents, in the language of Kant, a synthetic or an analytic judgment. It may, I think, be admitted that there is much cogency in this view; and, were Mathematics concerned with the elementary operations of arithmetic alone, it could fairly be held that the mathematician, like the practical man of the world, might without much risk shut his eyes and ears to the discussions of the philosophers on such points. The exactitude of such a proposition, in a suffi-

ciently definite sense for practical purposes, is empirically verifiable by sensuous intuition, whatever meaning the metaphysician may attach to it. But Mathematics cannot be built up from the operations of elementary arithmetic without the introduction of further conceptual elements. Except in certain very simple cases no process of measurement, such as the determination of an area or a volume, can be carried out with exactitude by a finite number of applications of the operations of arithmetic. The result to be obtained appears in the form of a limit, corresponding to an interminable sequence of arithmetical operations. The notion of 'limit,' in the definite form given to it by Cauchy and his followers, together with the closely related theory of the arithmetic continuum, and the notions of continuity and functionality, lie at the very heart of modern analysis. Essentially bound up with this central doctrine of limits is the concept of a non-finite set of entities, a concept which is not directly derivable from sensuous intuition, but which is nevertheless a necessary postulation in mathematical analysis. The conception of the infinite, in some form, is thus indispensable in Mathematics; and this conception requires precise characterisation by a scheme of exact definitions, prior to all the processes of deduction required in obtaining the detailed results of analysis. The formulation of this precise scheme gives an opening to differences of philosophical opinion which has led to a variety of views as to the proper character of those definitions which involve the concept of the infinite. Here is the point of divergence of opinion among mathematicians to which I have alluded above. Under what conditions is a non-finite aggregate of entities a properly defined object of mathematical thought, of such a character that no contradictions will arise in the theories based upon it? That is the question to which varying answers have been offered by different mathematical thinkers. No one answer of a completely general character has as yet met with universal acceptance. Physical intuition offers no answer to such a question; it is one which abstract thought alone can settle. It cannot be altogether avoided, because, without the notion of the infinite, at least in connection with the central conception of the 'limit,' mathematical analysis as a coherent body of thought falls to the ground.

Both in geometry and in analysis our standard of what constitutes a rigorous demonstration has in the course of the nineteenth century undergone an almost revolutionary change. That oldest text-book of science in the world, 'Euclid's Elements of Geometry,' has been popularly held for centuries to be the very model of deductive logical demonstration. Criticism has, however, largely invalidated this view. It appears that, at a large number of points, assumptions not included in the preliminary axioms and postulates are made use of. The fact that these assumptions usually escape notice is due to their nature and origin. Derived as they are from our spatial intuition, their very self-evidence has allowed them to be ignored, although their truth is not more obvious empirically than that of other assumptions derived from the same source which are included in the axioms and postulates explicitly stated as part of the foundation of Euclid's treatment of the subject. The method of superimposition, employed by Euclid with obvious reluctance, but forming an essential part of his treatment of geometry, is, when regarded from his point of view, open to most serious objections as regards its logical coherence. In analysis, as in geometry, the older methods of treatment consisted of processes of deduction eked out by the more or less surreptitious introduction, at numerous points in the subject, of assumptions only justifiable by spatial intuition. The result of this deviation from the purely deductive method was more disastrous in the case of analysis than in geometry, because it led to much actual error in the theory. For example, it was held until comparatively recently that a continuous function necessarily possesses a differential coefficient, on the ground that a curve always has a tangent. This we now know to be quite erroneous, when any reasonable definition of continuity is employed. The first step in the discovery of this error was made when it occurred to Ampère that the existence of the differential coefficient could only be asserted as a theorem requiring proof; and he himself published an attempt at such proof. The erroneous character of the former belief on this matter was most strikingly exhibited when Weierstrass produced a function which is everywhere continuous, but which nowhere possesses a differential coefficient; such functions can now be constructed *ad libitum*. It is not too much to say that no one of the general theorems of analysis is true without the introduction of limitations and conditions which were

entirely unknown to the discoverers of those theorems. It has been the task of mathematicians under the lead of such men as Cauchy, Riemann, Weierstrass, and G. Cantor, to carry out the work of reconstruction of mathematical analysis, to render explicit all the limitations of the truth of the general theorems, and to lay down the conditions of validity of the ordinary analytical operations. Physicists and others often maintain that this modern extreme precision amounts to an unnecessary and pedantic purism, because in all practical applications of Mathematics only such functions are of importance as exclude the remoter possibilities contemplated by theorists. Such objections leave the true mathematician unmoved; to him it is an intolerable defect that, in an order of ideas in which absolute exactitude is the guiding ideal, statements should be made, and processes employed, both of which are subject to unexpressed qualifications, as conditions of their truth or validity. The pure mathematician has developed a specialised conscience, extremely sensitive as regards sins against logical precision. The physicist, with his conscience hardened in this respect by the rough-and-tumble work of investigating the physical world, is apt to regard the more tender organ of the mathematician with that feeling of impatience, not unmingled with contempt, which the man of the world manifests for what he considers to be over-scrupulosity and unpracticality.

It is true that we cannot conceive how such a science as Mathematics could have come into existence apart from physical experience. But it is also true that physical percepts, as given directly in unanalysed experience, are wholly unfitted to form the basis of an exact science. Moreover, physical intuition fails altogether to afford any trustworthy guidance in connection with the concept of the infinite, which, as we have seen, is in some form indispensable in the formation of a coherent system of mathematical analysis. The hasty and uncritical extension to the region of the infinite of results which are true and often obvious in the region of the finite, has been a fruitful source of error in the past, and remains as a pitfall for the unwary student in the present. The notions derived from physical intuition must be transformed into a scheme of exact definitions and axioms before they are available for the mathematician, the necessary precision being contributed by the mind itself. A very remarkable fact in connection with this process of refinement of the rough data of experience is that it contains an element of arbitrariness, so that the result of the process is not necessarily unique. The most striking example of this want of uniqueness in the conceptual scheme so obtained is the case of geometry, in which it has been shown to be possible to set up various sets of axioms, each set self-consistent, but inconsistent with any other of the sets, and yet such that each set of axioms, at least under suitable limitations, leads to results consistent with our perception of actual space-relations. Allusion is here made, in particular, to the well-known geometries of Lobatchewsky and of Riemann, which differ from the geometry of Euclid in respect of the axiom of parallels, in place of which axioms inconsistent with that of Euclid and with one another are substituted. It is a matter of demonstration that any inconsistency which might be supposed to exist in the scheme known as hyperbolic geometry, or in that known as elliptic geometry, would necessarily entail the existence of a corresponding inconsistency in Euclid's set of axioms. The three geometries therefore, from the logical point of view, are completely on a par with one another. An interesting mathematical result is that all efforts to prove Euclid's axiom of parallels, *i.e.*, to deduce it from his other axioms, are doomed to necessary failure; this is of importance in view of the many efforts that have been made to obtain the proof referred to. When the question is raised which of these geometries is the true one, the kind of answer that will be given depends a good deal on the view taken of the relation of conceptual schemes in general to actual experience. It is maintained by M. Poincaré, for example, that the question which is the true scheme has no meaning; that it is, in fact, entirely a matter of convention and convenience which of these geometries is actually employed in connection with spatial measurements. To decide between them by a crucial test is impossible, because our space perceptions are not sufficiently exact in the mathematical sense to enable us to decide between the various axioms of parallels. Whatever views are taken as to the difficult questions that arise in this connection, the contemplation and study of schemes of geometry wider than that of Euclid, and some of them including Euclid's geometry as a special

case, is of great interest not only from the purely mathematical point of view, but also in relation to the general theory of knowledge, in that, owing to the results of this study, some change is necessitated in the views which have been held by philosophers as to what is known as Kant's space-problem.

The school of thought which has most emphasised the purely logical aspect of Mathematics is that which is represented in this country by Mr. Bertrand Russell and Dr. Whitehead, and which has distinguished adherents both in Europe and in America. The ideal of this school is a presentation of the whole of Mathematics as a deductive scheme in which are employed a certain limited number of indefinables and unprovable axioms, by means of a procedure in which all possibility of the illicit intrusion of extraneous elements into the deduction is excluded by the employment of a symbolism in which each symbol expresses a certain logical relation. This school receives its inspiration from a peculiar form of philosophic realism which, in its revolt from idealism, produces in the adherents of the school a strong tendency to ignore altogether the psychological implications in the movements of mathematical thought. This is carried so far that in their writings no explicit recognition is made of any psychological factors in the selection of the indefinables and in the formulation of the axioms upon which the whole structure of Mathematics is to be based. The actually worked-out part of their scheme has as yet reached only the mere fringe of modern Mathematics as a great detailed body of doctrine; but to any objection to the method on the ground of the prolixity of the treatment which would be necessary to carry it out far enough to enable it to embrace the various branches of Mathematics in all the wealth of their present development, it would probably be replied that the main point of interest is to establish in principle the possibility only of subsuming Pure Mathematics under a scheme of logistic. It is quite impossible for me here to attempt to discuss, even in outline, the tenets of this school, or even to deal with the interesting question of the possibility of setting up a final system of indefinables and axioms which shall suffice for all present and future developments of Mathematics.

I am very far from wishing to minimise the high philosophic interest of the attempt made by the Peano-Russell school to exhibit Mathematics as a scheme of deductive logic. I have myself emphasised above the necessity and importance of fitting the results of mathematical research in their final form into a framework of deduction, for the purpose of ensuring the complete precision and the verification of the various mathematical theories. At the same time it must be recognised that the purely deductive method is wholly inadequate as an instrument of research. Whatever view may be held as regards the place of psychological implications in a completed body of mathematical doctrine, in research the psychological factor is of paramount importance. The slightest acquaintance with the history of Mathematics establishes the fact that discoveries have seldom, or never, been made by purely deductive processes. The results are thrown into a purely deductive form after, and often long after, their discovery. In many cases the purely deductive form, in the full sense, is quite modern. The possession of a body of indefinables, axioms, or postulates, and symbols denoting logical relation, would, taken by itself, be wholly insufficient for the development of a mathematical theory. With these alone the mathematician would be unable to move a step. In face of an unlimited number of possible combinations a principle of selection of such as are of interest, a purposive element, and a perceptive faculty are essential for the development of anything new. In the process of discovery the chains in a sequence of logical deduction do not at first arise in their final order in the mind of the mathematical discoverer. He divines the results before they are established; he has an intuitive grasp of the general line of a demonstration long before he has filled in the details. A developed theory, or even a demonstration of a single theorem, is no more identical with a mere complex of syllogisms than a melody is identical with the mere sum of the musical notes employed in its composition. In each case the whole is something more than merely the sum of its parts; it has a unity of its own, and that unity must be, in some measure at least, discerned by its creator before the parts fall completely into their places. Logic is, so to speak, the grammar of Mathematics; but a knowledge of the rules of grammar and the letters of the alphabet would not be sufficient equipment to enable a man to write a book. There is much room for

individuality in the modes of mathematical discovery. Some great mathematicians have employed largely images derived from spatial intuition as a guide to their results; others appear wholly to have discarded such aids, and were led by a fine feeling for algebraic and other species of mathematical form. A certain tentative process is common, in which, by the aid of results known or obtained in special cases, generalisations are perceived and afterwards established, which take up into themselves all the special cases so employed. Most mathematicians leave some traces, in the final presentation of their work, of the scaffolding they have employed in building their edifices : some much more than others.

The difference between a mathematical theory in the making and as a finished product is, perhaps, most strikingly illustrated by the case of geometry, as presented in its most approved modern shape. It is not too much to say that geometry, reduced to a purely deductive form—as presented, for example, by Hilbert, or by some of the modern Italian school—has no necessary connection with space. The words 'point,' 'line,' 'plane' are employed to denote any entities whatever which satisfy certain prescribed conditions of relationship. Various premisses are postulated that would appear to be of a perfectly arbitrary nature, if we did not know how they had been suggested. In that division of the subject known as metric geometry, for example, axioms of congruency are assumed which, by their purely abstract character, avoid the very real difficulties that arise in this regard in reducing perceptual space-relations of measurements to a purely conceptual form. Such schemes, triumphs of constructive thought at its highest and most abstract level as they are, could never have been constructed apart from the space-perceptions that suggested them, although the concepts of spatial origin are transformed almost out of recognition. But what I want to call attention to here is that, apart from the basis of this geometry, mathematicians would never have been able to find their way through the details of the deductions without having continual recourse to the guidance given them by spatial intuition. If one attempts to follow one of the demonstrations of a particular theorem in the work of writers of this school, one would find it quite impossible to retain the steps of the process long enough to master the whole, without the aid of the very spatial suggestions which have been abstracted. This is perhaps sufficiently warranted by the fact that writers of this school find it necessary to provide their readers with figures, in order to avoid complete bewilderment in following the demonstrations, although the processes, being purely logical deductions from premisses of the nature I have described, deal only with entities which have no necessary similarity to anything indicated by the figures.

A most interesting account has been written by one of the greatest mathematicians of our time, M. Henri Poincaré, of the way in which he was led to some of his most important mathematical discoveries.[1] He describes the process of discovery as consisting of three stages : the first of these consists of a long effort of concentrated attention upon the problem in hand in all its bearings; during the second stage he is not consciously occupied with the subject at all, but at some quite unexpected moment the central idea which enables him to surmount the difficulties, the nature of which he had made clear to himself during the first stage, flashes suddenly into his consciousness. The third stage consists of the work of carrying out in detail and reducing to a connected form the results to which he is led by the light of his central idea; this stage, like the first, is one requiring conscious effort. This is, I think, clearly not a description of a purely deductive process; it is assuredly more interesting to the psychologist than to the logician. We have here the account of a complex of mental processes in which it is certain that the reduction to a scheme of precise logical deduction is the latest stage. After all, a mathematician is a human being, not a logic-engine. Who that has studied the works of such men as Euler, Lagrange, Cauchy, Riemann, Sophus Lie, and Weierstrass, can doubt that a great mathematician is a great artist? The faculties possessed by such men, varying greatly in kind and degree with the individual, are analogous to those requisite for constructive art. Not every great mathematician possesses in a specially high degree that critical faculty which finds its employment in the perfection of form, in conformity with the

[1] See the *Revue du Mois* for 1908.

ideal of logical completeness; but every great mathematician possesses the rarer faculty of constructive imagination.

The actual evolution of mathematical theories proceeds by a process of induction strictly analogous to the method of induction employed in building up the physical sciences; observation, comparison, classification, trial, and generalisation are essential in both cases. Not only are special results, obtained independently of one another, frequently seen to be really included in some generalisation, but branches of the subject which have been developed quite independently of one another are sometimes found to have connections which enable them to be synthesised in one single body of doctrine. The essential nature of mathematical thought manifests itself in the discernment of fundamental identity in the mathematical aspects of what are superficially very different domains. A striking example of this species of immanent identity of mathematical form was exhibited by the discovery of that distinguished mathematician, our General Secretary, Major Macmahon, that all possible Latin squares are capable of enumeration by the consideration of certain differential operators. Here we have a case in which an enumeration, which appears to be not amenable to direct treatment, can actually be carried out in a simple manner when the underlying identity of the operation is recognised with that involved in certain operations due to differential operators, the calculus of which belongs superficially to a wholly different region of thought from that relating to Latin squares. The modern abstract theory of groups affords a very important illustration of this point; all sets of operations, whatever be their concrete character, which have the same group, are from the point of view of the abstract theory identical, and an analysis of the properties of the abstract group gives results which are applicable to all the actual sets of operations, however diverse their character, which are dominated by the one group. The characteristic feature of any special geometrical scheme is known when the group of transformations which leave unaltered certain relations of figures has been assigned. Two schemes in which the space elements may be quite different have this fundamental identity, provided they have the same group; every special theorem is then capable of interpretation as a property of figures either in the one or in the other geometry. The mathematical physicist is familiar with the fact that a single mathematical theory is often capable of interpretation in relation to a variety of physical phenomena. In some instances a mathematical formulation, as in some fashion representing observed facts, has survived the physical theory it was originally devised to represent. In the case of electromagnetic and optical theory, there appears to be reason for trusting the equations, even when the proper physical interpretation of some of the vectors appearing in them is a matter of uncertainty and gives rise to much difference of opinion; another instance of the fundamental nature of mathematical form.

One of the most general mathematical conceptions is that of functional relationship, or 'functionality.' Starting originally from simple cases such as a function represented by a power of a variable, this conception has, under the pressure of the needs of expanding mathematical theories, gradually attained the completeness of generality which it possesses at the present time. The opinion appears to be gaining ground that this very general conception of functionality, born on mathematical ground, is destined to supersede the narrower notion of causation, traditional in connection with the natural sciences. As an abstract formulation of the idea of determination in its most general sense, the notion of functionality includes and transcends the more special notion of causation as a one-sided determination of future phenomena by means of present conditions; it can be used to express the fact of the subsumption under a general law of past, present, and future alike, in a sequence of phenomena. From this point of view the remark of Huxley that Mathematics 'knows nothing of causation' could only be taken to express the whole truth, if by the term 'causation' is understood 'efficient causation.' The latter notion has, however, in recent times been to an increasing extent regarded as just as irrelevant in the natural sciences as it is in Mathematics; the idea of thorough-going determinancy, in accordance with formal law, being thought to be alone significant in either domain.

The observations I have made in the present address have, in the main, had reference to Mathematics as a living and growing science related to and permeating other great departments of knowledge. The small remaining space at

my disposal I propose to devote to a few words about some matters connected with the teaching of the more elementary parts of Mathematics. Of late years a new spirit has come over the mathematical teaching in many of our institutions, due in no small measure to the reforming zeal of our General Treasurer, Professor John Perry. The changes that have been made followed a recognition of the fact that the abstract mode of treatment of the subject that had been traditional was not only wholly unsuitable as a training for physicists and engineers, but was also to a large extent a failure in relation to general education, because it neglected to bring out clearly the bearing of the subject on the concrete side of things. With the general principle that a much less abstract mode of treatment than was formerly customary is desirable for a variety of reasons, I am in complete accord. It is a sound educational principle that instruction should begin with the concrete side, and should only gradually introduce the more general and abstract aspects of the subject; an abstract treatment on a purely logical basis being reserved only for that highest and latest stage which will be reached only by a small minority of students. At the same time I think there are some serious dangers connected with the movement towards making the teaching of Mathematics more practical than formerly, and I do not think that, in making the recent changes in the modes of teaching, these dangers have always been successfully avoided.

Geometry and mechanics are both subjects with two sides : on the one side, the observational, they are physical sciences; on the other side, the abstract and deductive, they are branches of Pure Mathematics. The older traditional treatment of these subjects has been of a mixed character, in which deduction and induction occurred side by side throughout, but far too much stress was laid upon the deductive side, especially in the earlier stages of instruction. It is the proportion of the two elements in the mixture that has been altered by the changed methods of instruction of the newer school of teachers. In the earliest teaching of the subjects they should, I believe, be treated wholly as observational studies. At a later stage a mixed treatment must be employed, observation and deduction going hand in hand, more stress being, however, laid on the observational side than was formerly customary. This mixed treatment leaves much opening for variety of method; its character must depend to a large extent on the age and general mental development of the pupils; it should allow free scope for the individual methods of various teachers as suggested to those teachers by experience. Attempts to fix too rigidly any particular order of treatment of these subjects are much to be deprecated, and, unfortunately, such attempts are now being made. To have escaped from the thraldom of Euclid will avail little if the study of geometry in all the schools is to fall under the domination of some other rigidly prescribed scheme.

There are at the present time some signs of reaction against the recent movement of reform in the teaching of geometry. It is found that the lack of a regular order in the sequence of propositions increases the difficulty of the examiner in appraising the performance of the candidates, and in standardising the results of examinations. That this is true may well be believed, and it was indeed foreseen by many of those who took part in bringing about the dethronement of Euclid as a text-book. From the point of view of the examiner it is without doubt an enormous simplification if all the students have learned the subject in the same order, and have studied the same text-book. But, admitting this fact, ought decisive weight to be allowed to it? I am decidedly of opinion that it ought not. I think the convenience of the examiner, and even precision in the results of examinations, ought unhesitatingly to be sacrificed when they are in conflict—as I believe they are in this case—with the vastly more important interests of education. Of the many evils which our examination system has inflicted upon us, the central one has consisted in forcing our school and university teaching into moulds determined not by the true interests of education, but by the mechanical exigencies of the examination syllabus. The examiner has thus exercised a potent influence in discouraging initiative and individuality of method on the part of the teacher; he has robbed the teacher of that freedom which is essential for any high degree of efficiency. An objection of a different character to the newer modes of teaching geometry has been frequently made of late. It is said that the students are induced to accept and reproduce, as proofs of theorems, arguments which are not really proofs, and thus that the logical

training which should be imparted by a study of geometry is vitiated. If this objection really implies a demand for a purely deductive treatment of the subject, I think some of those who raise it hardly realise all that would be involved in the complete satisfaction of their requirement. I have already remarked that Euclid's treatment of the subject is not rigorous as regards logic. Owing to the recent exploration of the foundations of geometry we possess at the present time tolerably satisfactory methods of purely deductive treatment of the subject; in regard to mechanics, notwithstanding the valuable work of Mach, Herz, and others, this is not yet the case. But, in the schemes of purely deductive geometry, the systems of axioms and postulates are far from being of a very simple character; their real nature, and the necessity for many of them, can only be appreciated at a much later stage in mathematical education than the one of which I am speaking. A purely logical treatment is the highest stage in the training of the mathematician, and is wholly unsuitable—and, indeed, quite impossible—in those stages beyond which the great majority of students never pass. It can then, in the case of all students, except a few advanced ones in the universities, only be a question of degree how far the purely logical factor in the proofs of propositions shall be modified by the introduction of elements derived from observation or spatial intuition. If the freedom of teaching which I have advocated be allowed, it will be open to those teachers who find it advisable in the interests of their students to emphasise the logical side of their teaching to do so; and it is certainly of value in all cases to draw the attention of students to those points in a proof where the intuitional element enters. I draw, then, the conclusion that a mixed treatment of geometry, as of mechanics, must prevail in the future, as it has done in the past, but that the proportion of the observational or intuitional factor to the logical one must vary in accordance with the needs and intellectual attainments of the students, and that a large measure of freedom of judgment in this regard should be left to the teacher.

The great and increasing importance of a knowledge of the differential and integral calculus for students of engineering and other branches of physical science has led to the publication during the last few years of a considerable number of text-books on this subject intended for the use of such students. Some of these text-books are excellent, and their authors, by a skilful insistence on the principles of the subject, have done their utmost to guard against the very real dangers which attend attempts to adapt such a subject to the practical needs of engineers and others. It is quite true that a great mass of detail which has gradually come to form part—often much too large a part—of the material of the student of Mathematics, may with great advantage be ignored by those whose main study is to be engineering science or physics. Yet it cannot be too strongly insisted on that a firm grasp of the principles, as distinct from the mere processes of calculation, is essential if Mathematics is to be a tool really useful to the engineer and the physicist. There is a danger, which experience has shown to be only too real, that such students may learn to regard Mathematics as consisting merely of formulæ and of rules which provide the means of performing the numerical computations necessary for solving certain categories of problems which occur in the practical sciences. Apart from the deplorable effect, on the educational side, of degrading Mathematics to this level, the practical effect of reducing it to a number of rule-of-thumb processes can only be to make those who learn it in so unintelligent a manner incapable of applying mathematical methods to any practical problem in which the data differ even slightly from those in the model problems which they have studied. Only a firm grasp of the principles will give the necessary freedom in handling the methods of Mathematics required for the various practical problems in the solution of which they are essential.

The following Papers were then read :—

1. *Positive Rays.* By Professor Sir J. J. Thomson, *F.R.S.*

The investigation of the positive rays which are produced when the electric discharge passes through a tube filled with gas at a low pressure is much facilitated by using very large tubes. With large tubes, in which there is room

for the dark space next the cathode to attain large dimensions before reaching the walls of the tube, the pressure may be reduced much lower without risk of sparking through the tube than is possible with small tubes, and hence many phases of the discharge can be investigated which either do not exist or are inconspicuous when the tubes are small and the pressure necessarily high. The author has used tubes with volumes as large as eleven litres, but tubes made of two-litre flasks such as are used for boiling-point determinations are large enough, if the anode is suitably placed, to show the various types of positive rays.

With these tubes the following types of rays, passing through a hole in the cathode, can be made out :—

1. Rays which are not deflected either by magnetic or electric forces.

2. Secondary rays produced by rays of type (1). These are deflected by electric and magnetic forces; they have a constant velocity of about 2×10^8 cms. per sec., which does not change, however the pressure in the tube or the potential difference between the electrodes may be altered. The value of e/m for these rays has the constant value 10^4.

These secondary positive rays are accompanied by negatively changed ones which have the same velocity and the same numerical value of e/m as the positive ones.

In small tubes the only rays which are prominent are those of types (1) and (2).

3. In addition to the rays of the preceding types, there are rays which are characteristic of the gases in the tube. These are only conspicuous when the pressure is low. The velocity of rays of this type, unlike that of the preceding type, depends upon the potential difference between the electrodes. When there are several gases in the tubes—say, hydrogen, air, helium—the maximum kinetic energy of the rays corresponding to each of these gases is the same, and seems to be that due to a fall through the potential difference between the negative of low and the cathode. The value of e/m for the rays from different gases is inversely proportioned to the atomic weight of the gas from which the rays are derived. Thus these rays are probably atoms of the gas carrying one unit of positive charge; in the case of hydrogen there seem to be rays corresponding to the molecule as well as to the atom.

The author has observed rays of this type corresponding to all the elements which have as yet been introduced into his tubes. These include hydrogen, helium, air, carbon, neon, and mercury. Other elements are in course of investigation.

Some, but not all, of these rays have negatively charged rays connected with them, resembling in this respect the secondary rays of type (2). The rays from air and mercury vapour have their negative constituents, while the negative rays corresponding to the hydrogen molecule, to the atoms of helium, carbon, and neon, have not been detected.

There is a considerable range in the velocities of the rays from the same gas, though when the pressure is very low the greater part seem to be moving with nearly the maximum velocity.

The rays corresponding to the different atoms can be separated by deflecting them by magnetic and electric forces; if after deflection they fall on a screen covered with a phosphorescent substance, each kind of ray produces under the simultaneous action of electric and magnetic forces a separate band on the phosphorescent screen forming a kind of spectrum. The tubes I worked with were not specially designed to allow the most intense magnetic fields possible to be applied to the rays, and I was not sure when air was in the tube I could see separate bands corresponding to nitrogen and oxygen; but when the air was replaced by carbon monoxide, two separate bands, one corresponding to carbon and the other to oxygen, could clearly be seen. Experiments are in progress with tubes designed so that exceedingly intense magnetic fields may be applied to the rays, for the purpose of using this method to analyse the gas in the tube and to measure the atomic weights of the constituents. As exceedingly small quantities of gas may be dealt with in this way, it appears probable that interesting results may follow from the application of this method to the analysis of the gases in vacuum tubes.

4. The fourth type of ray is the one I have previously called 'retrograde

rays.' These travel away from the cathode in the same direction as the cathode rays; these rays are of types (1) and (2). I have not succeeeded in detecting rays of type (3) among these rays. The retrograde rays have negative constituents.

2. *A New Spectrophotometer of the Hüfner Type.* By R. A. Houstoun, *M.A., Ph.D., D.Sc.*

This instrument consists of a spectroscope, the ordinary eyepiece of which has been replaced by an eyepiece containing a glass Thompson prism and in front of the slit of which is fixed a prism of special design made of glass and Iceland spar. This prism performs the double function of dividing the field of view into halves which touch each other sharply, and of polarising these halves at right angles to each other. The halves are matched by rotating the nicol eyepiece. The instrument can be arranged for use as an ordinary spectroscope in one minute by removing the special prism and substituting the ordinary eyepiece. It has the advantage over other Hüfner spectrophotometers that any dispersion prism may be used with it. It has been used for three researches during the past two years, and has proved accurate, free from systematic error, and very suitable for measuring the intensity of weak lights.

3. *A New and Simple Means of producing Interference Bands.* *By* R. A. Houstoun, *M.A., Ph.D., D.Sc.*

If a right-angled isosceles glass prism the right angle of which is a few minutes short of 90° is placed in front of a slit, two virtual images of the slit are formed behind the prism, and these produce interference bands in front of the prism. The experiment is being used as a student's exercise in the physical laboratory of the University of Glasgow. The method was at first thought to be new, but has recently been anticipated in Berlin.

4. *A New Gyroscopic Apparatus.* *By* Professor A. E. H. Love, *F.R.S.*

FRIDAY, SEPTEMBER 2.

Joint Meeting with Section B.

Discussion on Combustion.—See Reports, *p.* 501.

The following Papers and Report were then read :—

1. *The Molecular Weight of Radium Emanation.* *By* Sir William Ramsay, *K.C.B., F.R.S., and* Dr. R. W. Gray.

2. *On the Number of Electrons in the Atom.* *By* Dr. J. A. Crowther.

The present experiments were made to determine, by means of experiments in the β-rays, the number of electrons in the atom.

Professor Sir J. J. Thomson has recently calculated the mean deflection ϕ experienced by a β-particle of known velocity in passing through a thickness t of material. The summation is performed by a theorem due to Lord Rayleigh, which leads to the relationship

$$\phi/\sqrt{t}=c$$

where c is a constant involving only the number of electrons in the atom of

the substance, and known constants. The accuracy of this relationship has been very carefully tested by experiment.

The expression obtained for c depends upon the assumptions made as to the nature of positive electricity. Two expressions have been obtained—

(i) On the assumption that the positive electricity in the atom occupies a volume comparable with that of the atom; (ii) that it is divided into small units comparable in size with the negative electron.

Experimental determinations have been made of the ratio $\phi/\sqrt{t}$ for different elements and the corresponding number of electrons calculated. The appended table gives the number of electrons in the atom divided by the corresponding atomic weight.

It will be seen that the numbers in the first column are practically constant at a mean value—three. The numbers in the second column increase rapidly with the atomic weight. From experiments on the scattering of Röntgen rays it is almost certain that the number of electrons in the atom is proportional to the atomic weight, as given by our first assumption. Thus we conclude that the positive electrification occupies a volume comparable with that of the atom, and that the number of electrons in an atom is three times the atomic weight.

Ratio of the Number of Electrons in the Atom to Atomic Weight.

Element.	I.	II.
Carbon	3·32	3·7
Aluminium	3·07	5·8
Copper	2·87	12·0
Silver	2·96	19·2
Platinum	3·12	33·5

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3. *On the Attraction Constant of a Molecule of a Compound and its Chemical Properties.* By R. D. Kleeman, *D.Sc., B.A.*

The writer has previously deduced from surface tension and latent heat data that the attraction between two molecules of the same kind is $\frac{K}{z^5}(\Sigma\sqrt{m_1})^2$, where z is the distance between the molecules, and $\Sigma\sqrt{m_1}$ is the sum of the square roots of the atomic weights of the atoms of a molecule, and K is a quantity whose exact form is not known except that it has the same value for all substances at corresponding temperatures and may therefore be a function of the distance between the molecules and the temperature. The quantity $\Sigma\sqrt{m_1}$ will be referred to as the attraction constant of the molecule. It was now pointed out that it can be shown strictly mathematically that the law of attraction cannot be completely determined from surface tensions or latent heat data. The law deduced must contain an unknown function of the distance between the molecules and the temperature. It follows, therefore, that if we assume a law of attraction between molecules and deduce from it a formula for the surface tension or latent, and find that it fits the facts, it does not therefore follow that the law assumed is correct. In order to be on safe ground it is necessary that the law deduced should contain an unknown function. Now this is the case with the law given above, the exact nature of K being not known. Further, since K is the same for all substances at corresponding temperatures it does not contain $\Sigma\sqrt{m_1}$, and the chemical attraction of a molecule is therefore proportional to $\Sigma\sqrt{m_1}$, and this result should be true.

The attraction constants of the atoms of a molecule of a compound we would expect to be connected with its chemical properties. Thus the writer found that the properties of the quantity $\frac{Tc}{\Sigma\sqrt{m_1}}$ of a substance, where Tc denotes the critical temperature, run parallel with its purely chemical properties. Thus the value of this quantity is constant for a compound and its substitution products when an atom is

replaced by an atom. Further, if we write $A - B = \frac{Tc}{\Sigma\sqrt{m_1}}$, where B denotes the chemical formula of a substance, the quantities for which B stands and the quantity A have the same values for a group of substances possessing similar properties, but which vary from group to group. Thus, for example, in the case of the esters we would have $A - (20 + \alpha(C + 2H)) = \frac{Tc}{\Sigma\sqrt{m_1}}$, which may be written $A_1 - \alpha B_1 = \frac{Tc}{\Sigma\sqrt{m_1}}$, where α denotes an integer. The values of A_1 and B_1 are found to be the same for each ester.

The various chemical compounds can be divided into groups in the above ways, and it is found that this grouping coincides with that obtained from purely chemical considerations. The amines thus fall into three groups corresponding to the primary, secondary, and tertiary amines. The nitrites fall into a group, and so also do the ethers, the primary alcohols, and the secondary alcohols (omitting two alcohols which we know are, to a great extent, polymerised). The study of the properties of the quantity $\frac{Tc}{\Sigma\sqrt{m_1}}$ may therefore be of great assistance in the classification of chemical compounds into groups, and to obtain various other connections between the compounds.

4. *Report on Solubility. By* Dr. J. V. Eyre.—See Reports, p. 425.

5. *The Deduction of Hydration Values of Acids from the Rate at which they induce Hydrolysis. By* F. P. Worley.

Mathematical Department.

The following Papers and Reports were read :—

1. *On Functions derived from Complete and Incomplete Lattices in Two Dimensions and the Derivation there from of Functions which enumerate the Two Dimensional Partition of Numbers. By* Major P. A. MacMahon, *F.R.S.*

2. *On a certain Permutation Group. By* Dr. H. F. Baker, *F.R.S.*

If n different letters be written down in a certain order and then rearranged, by writing the last first, the first second, the last but one third, the second fourth, and so on, and this rule of rearrangement be then again applied, and so on repeatedly, required to find the number of rearrangements before the original order is regained.

For instance, the set of six letters gives in turn by this rule :—

a_1	a_2	a_3	a_4	a_5	a_6	or say	(6)	(1)	(5)	(2)	(4)	(3)
a_6	a_1	a_5	a_2	a_4	a_3		(3)	(6)	(4)	(1)	(2)	(5)
a_3	a_6	a_4	a_1	a_2	a_5		(5)	(3)	(2)	(6)	(1)	(4)
a_5	a_3	a_2	a_6	a_1	a_4		(4)	(5)	(1)	(3)	(6)	(2)
a_4	a_5	a_1	a_3	a_6	a_2		(2)	(4)	(6)	(5)	(3)	(1)
a_2	a_4	a_6	a_5	a_3	a_1		(1)	(2)	(3)	(4)	(5)	(6)
a_1	a_2	a_3	a_4	a_5	a_6							

so that the original arrangement is regained after six changes.

More generally writing the first two arrangements

$$\begin{array}{cccccccc} a_1 & a_2 & a_3 & \ldots & a_{n-2} & a_{n-1} & a_n \\ b_1 & b_2 & b_3 & \ldots & b_{n-2} & b_{n-1} & b_n \end{array}$$

we see that

$$b_1 = a_n,\ b_2 = a_1,\ b_3 = a_{n-1},\ \ldots\ldots,\ b_{2i} = a_i,\ b_{2i+1} = a_{n-i},\ \ldots$$

Hence if any column of the completed scheme be read upwards from the last row $a_1, a_2, \ldots, a_n$, the rule for the suffixes is to place above a_i the letter a_j where $j=2i$ unless $2i>n$, and $j=2n+1-2i$ in case $2i>n$, in which case $2n+1-2i \leqq n$.

As another example suppose $n=7$; the scheme, writing only the suffixes, is then

1	2	3	4	5	6	7
7	1	6	2	5	3	4
4	7	3	1	5	6	2
2	4	6	7	5	3	1
1	2	3	4	5	6	7

and there are four rearrangements; the column of 5 remains unaltered and two columns consist of 3, 6 repeated. The table thus gives a partition of 7 into $4+2+1$, in which each number after 4 divides 4.

In general we can prove that *the number of substitution in the group is the least number r which is such that one of the two numbers 2^r-1, 2^r+1 divides by $2n+1$.*

For suppose $2^r+\epsilon=(2n+1)M$, where ϵ is $+1$ or -1; let 2^{λ_1} be the least power of 2 greater than the odd number M, 2^{λ_2} the least power of 2 greater than the odd number $2^{\lambda_1}-M$, and so on; thence we can write

$$M=2^{\lambda_1}-2^{\lambda_2}+2^{\lambda_3}- \;.\;.\; -2^{\lambda_{1}h}+1, \text{ when } \epsilon=+1$$

or

$$M=2^{\lambda_1}-2^{\lambda_2}+2^{\lambda_3}- \;.\;.\; +2^{\lambda_{1}k}-1, \text{ when } \epsilon=-1,$$

with $\lambda_1>\lambda_2>\lambda_3 \ldots$, the identity $1=2-1$ being used if necessary to give the required last term. It can then be seen, if N denote $2n+1$, that the numbers

$$H_{2s}=2^{-\lambda_{2s-1}}\{(2^{\lambda_1}-2^{\lambda_2}+ \;.\;.\; +2^{\lambda_{2s-1}})N-2^r\}$$

$$H_{2s+1}=2^{-\lambda_{2s}}\{-(2^{\lambda_1}-2^{\lambda_2}+ \;.\;.\;.\; -2^{\lambda_{2s}})N+2^r\}$$

are positive integers such that

$$2^{\lambda_{p-1}-\lambda_p}H_p+1 \leqq N \leqq 2^{\lambda_{p-1}-\lambda_p+1}H_p+1.$$

Beginning now with the number 1, apply the rule obtained above, $j=2i$ when $2i\leqq n$, $j=N-2i$ when $2i>n$; it will then be found that we obtain in succession the numbers

$$\begin{array}{l} 1,\ 2,\ 2^2,\ 2^3,\ \ldots\ 2^{r-\lambda_1-1}, \\ N-2^{r-\lambda_1},\ 2(N-2^{r-\lambda_1}),\ \ldots\ 2^{\lambda_1-\lambda_2-1}(N-2^{r-\lambda_1}), \\ H_3,\ 2H_3,\ \ldots\ 2^{\lambda_2-\lambda_3-1}(H_3), \\ H_4,\ 2H_4,\ \ldots\ 2^{\lambda_3-\lambda_4-1}H_1, \end{array}$$

and so on, the last element of the last row being n itself.

The number of these numbers is r; though beginning with 1 and ending with n they do not generally consist of all the numbers from 1 to n. In particular if N be a composite number, no divisor of N will occur in the series. Let d be a divisor of N, and $N=df$; the equation $2^r+\epsilon=NM$ is the same as $2^r+\epsilon=fdM=fK$, say. Suppose r_1 is the least number such that one of the two numbers $2^{r_1}+1$, $2^{r_1}-1$ divides by f, say $2^{r_1}+\epsilon_1=fM_1$, so that $r_1\leqq r$. We may then form a cycle, 1, 2, 4, $\ldots \frac{1}{2}(f-1)$, of r_1 numbers, by the rule that after any number σ of this cycle shall follow $\tau=2\sigma$ so long as $2\sigma\leqq\frac{1}{2}(f-1)$, and the number $f-2\sigma$ when $2\sigma>\frac{1}{2}(f-1)$; if we put $i=d\sigma$, $j=d\tau$, these rules are equivalent to $j=2i$ or $j=N-2i$; applied to d, they give a cycle $d, 2d, 4d, \ldots$, ending with $\frac{1}{2}(N-d)$, consisting of r_1 numbers formed by the same rule as was originally used. If we put $r=\mu r_1-\lambda$, where $0\leqq\lambda<r_1$, the congruence $2^{r_1}\equiv\pm1 \pmod{f}$ gives, since $2^r\equiv\pm1 \pmod{f}$, also $2^\lambda\equiv\pm1 \pmod{f}$ and hence $\lambda=0$. Thus r divides by r_1. Further, $2^{r_1}\equiv\pm1 \pmod{f}$ gives $2^r\equiv(\pm1)^{r/r_1} \pmod{f}$, and $(\pm1)^{r/r_1}$ can be -1 only if ±1 is really -1 and r/r_1 is odd; this does arise.

Suppose next that p is any number $<n$ which is not a divisor of N and does not occur in the original cycle 1, 2, 4, . . ., . Let t be the least number such that one of the two numbers $(2^t\pm1)p$ is divisible by N, and put

$$(2^t+\epsilon)p=(2^{\mu_1}-2^{\mu_2}+ \;.\;.\;.\; +\epsilon)N,$$

where

$$2^{\mu_1} > \frac{(2^t+\epsilon)p}{N},\ 2^{\mu_1}-1 < \frac{(2^t+\epsilon)p}{N},\ 2^{\mu_1}-2^{\mu_2} < \frac{(2^t+\epsilon)p}{N},\ 2^{\mu_1}-2^{\mu_2}-1 > \frac{(2^t+\epsilon)p}{N},$$

and so on, just as before, and the number of terms in the value for $\frac{(2^t+\epsilon)p}{N}$ is even when $\epsilon = +1$, and otherwise odd. Then putting

$$k_{2s} = \{(2^{\mu_1} - 2^{\mu_2} + \ \ldots\ + 2^{\mu_{2s-1}})N - 2^t p\}2^{-\mu_{2s-1}};$$
$$k_{2s+1} = \{-(2^{\mu_1} - 2^{\mu_2} + \ \ldots\ - 2^{\mu_{2s}})N + 2^t p\}2^{-\mu_{2s}},$$

we find as before that the cycle beginning with the number p, and proceeding as before according to the rule $j = 2i$, or $j = N - 2i$, is given by the series

$$\begin{array}{l} p,\ 2p,\ \ldots,\ 2^{t-\mu_1-1}p, \\ N-2^{t-\mu_1}p,\ 2(N-2^{t-\mu_1}p),\ \ldots,\ 2^{\mu_1-\mu_2-1}(N-2^{t-\mu_1}), \\ K_3,\ 2K_3,\ \ldots,\ 2^{\mu_2-\mu_3-1}K_3, \\ K_4,\ 2K_4,\ \ldots,\ 2^{\mu_3-\mu_4-1}K_4, \\ \ldots, \end{array}$$

and consists of t numbers. And it is not difficult to show that $t = r$ or is a divisor of r.

For an example of some length it may be verified that when n is 412 we have nineteen cycles of each 20 numbers, one cycle of 10 numbers, three cycles of each 5 numbers, one cycle of 4 numbers, one cycle of 2 numbers, and one number unaltered throughout a column. Thus there are 20 permutations in the group formed with 412 letters, and we have the partition

$$412 = 20 + 20 + \ \ldots\ \text{(nineteen times)} + 10 + 5 + 5 + 5 + 4 + 2 + 1.$$

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3. *On the Trisection of the Elliptic Functions.* *By* Dr. H. F. Baker, *F.R.S.*

A quartic equation for which the two conditions are satisfied, (1) that the invariant of the second degree vanishes, (2) that the sum of the roots is zero, may be supposed to have this form :—

$$f(x) = x^4 - \frac{1}{2}g_2x^2 - g_3x - \frac{1}{48}g_2^2 = 0.$$

The root of this equation may be supposed to be

$$x_1 = A(1-\mu)^2,\ x_2 = A(1-\mu\epsilon)^2,\ x_3 = A(1-\mu\epsilon^2)^2,\ x_4 = -3A,$$

where ϵ is an imaginary cube root of unity, and μ, A are such that

$$\frac{\mu^3(\mu^3+8)^3}{4^3(1-\mu^3)^3} = \frac{27g_3^2 - g_2^3}{g_2^3},\quad A = -\frac{12g_3}{g_2}\ \frac{1-\mu^3}{8+20\mu^3-\mu^6}.$$

Hence these roots are connected by the two equations

$$\sqrt{x_1} + \epsilon\sqrt{x_2} + \epsilon^2\sqrt{x_3} = 0,\quad \sqrt{x_4} + \epsilon^2\sqrt{x_1} - \epsilon\sqrt{x_2} = 0,$$

besides two others linearly deducible from these.

If the original quartic equation be transformed by putting $x^1 = (px+q)(rx+s)$, the quadric invariant of the new equation in x^1 will also vanish; if the sum of the four values of x^1 is also zero, it is easily found that x^1 is an arbitrary multiple of

$$f^1(\lambda) - \frac{4f(\lambda)}{\lambda - x},$$

in which λ is arbitrary, and $f^1(\lambda) = 4\lambda^3 - g_2\lambda - g_3$. Thus the square roots of the four expressions obtained from this by replacing in turn x by x_1, x_2, x_3, x_4, are likewise connected by two linear equations. A particular case is obtained by taking λ equal to one of the roots of $f^1(\lambda) = 0$, say e; then we obtain the equations

$$\frac{1}{\sqrt{x_1-e}} + \frac{\epsilon}{\sqrt{x_2-e}} + \frac{\epsilon^2}{\sqrt{x_3-e}} = 0,\quad \frac{1}{\sqrt{x_4-e}} + \frac{\epsilon^2}{\sqrt{x_1-e}} - \frac{\epsilon}{\sqrt{x_2-e}} = 0.$$

Retaining, however, an arbitrary value for λ, and dividing $f(\lambda)$ by $\lambda - x$, we infer that if

$$\xi_i = \lambda^2 x_i + \lambda(x_i^2 - \frac{1}{4}g_2) + x_i^3 - \frac{1}{2}g_2 x_i - \frac{3}{4}g_3,$$

then

$$\sqrt{\xi_1} + \epsilon\sqrt{\xi_2} + \epsilon^2\sqrt{\xi_3} = 0, \quad \sqrt{\xi_4} + \epsilon^2\sqrt{\xi_1} - \epsilon\sqrt{\xi_2} = 0,$$

for all values of λ. With the usual symbolical notation the general value of ξ may be written $\xi \,\|\, f_\lambda^3 f_x/(\lambda x)$.

The application of these remarks to the trisection of the elliptic functions arises from the fact that, with the usual notation, the four quantities

$$p\left(\frac{2\omega}{3}\right), \quad p\left(\frac{2\omega^1}{3}\right), \quad p\left(\frac{2\omega+2\omega^1}{3}\right), \quad p\left(\frac{4\omega+2\omega^1}{3}\right)$$

satisfy the quartic equation $f(x) = 0$.

Also it is easily found that the four quantities

$$\frac{1}{p^{12}\left(\frac{2\omega}{3}\right)}, \quad \frac{1}{p^{12}\left(\frac{2\omega^1}{2}\right)}, \quad \frac{1}{p^{12}\left(\frac{2\omega+2\omega^1}{3}\right)}, \quad \frac{1}{p^{12}\left(\frac{4\omega+2\omega^1}{3}\right)},$$

satisfy the equation

$$\mu^4 - \frac{18}{\Delta}\mu^2 + \frac{216}{\Delta^2}g_3\mu - \frac{27}{\Delta^2} = 0,$$

where $\Delta = 27g_3^2 - g_2^3$; to this similar remarks apply, so that, for instance, we have

$$\frac{1}{p^1\left(\frac{2\omega}{3}\right)} + \frac{\sigma\epsilon}{p^1\left(\frac{2\omega^1}{3}\right)} \pm \frac{\epsilon^2}{p^1\left(\frac{2\omega+2\omega^1}{3}\right)} = 0,$$

$$\pm \frac{1}{p^1\left(\frac{4\omega+2\omega^1}{3}\right)} + \frac{\epsilon^2}{p^1\left(\frac{2\omega}{3}\right)} - \frac{\sigma\epsilon}{p^1\left(\frac{2\omega^1}{3}\right)} = 0,$$

where $\sigma = \pm 1$.

4. *On the Convergence of certain Series used in Electron Theory.* *By* Professor A. W. Conway.

If $r(t)$ denotes the distance of the point x, y, z from the moving point (which for simplicity we may regard as moving in a right line) whose co-ordinates are $0, 0, f(t)$, then it is known that the equation $C(t-T) = r(T)$, where C is the speed of radiation, possesses a real root T between 0 and t, provided that the speed of the moving point is less than C and that $Ct > r(0)$. The series

$$r^{-1} + \frac{C^{-2}}{2!}\frac{\delta^2}{\delta t^2}r - \frac{C^{-3}}{3!}\frac{\delta^3}{\delta t^3}r^2 + \text{ \&c.}$$

if convergent, represent the potential of a moving point. Its convergence (and that of other series of this type) may be established by using a complex integral, $\int \frac{du}{\{C(t-u) - r(u)\}r(u)}$ around a circle in the u-plane about the point t as centre, and of such a radius that $C|(t-u)| > |r(u)|$ on its boundary. In the case examined the conditions for convergence are the same as those for a real root of $C(t-T) = r(T)$, where $t > T > 0$.

5. *Two Notes on Theory of Numbers.* *By* Lieut.-Colonel Allan Cunningham, *R.E.*

Factorisation of $N = (2^{77}+1)$.

$N = N_1 \,.\, N_7 \,.\, N_{11} \,.\, N_{77}$; where
$N_1 = (2^1+1) = 3$; $N_7 = (2^7+1) \div N_1 = 43$; $N_{11} = (2^{11}+1) \div N_1 = 683$;
$N_{77} = (2^{77}+1)(2+1) \div (2^7+1)(2^{11}+1) = 617 \,.\, 78233 \,.\, 35532364099$;

[The last 11-figure factor is *prime*].

Is (2^p-2) *divisible by* p^2 [*p a prime*] *?*

It is believed that no case is known of $2^p-2\equiv 0 \pmod{p^2}$ with p prime. It is *stated* by M. F. Proth[1] that $2^p-2\not\equiv 0 \pmod{p^2}$, with p prime; but no proof is given, no proof is quoted, no statement made of existence of any proof. At present it can only be asserted that it is *probably true*. To test this the writer has *tried all prime divisors* $p \not> 1000$ and finds that $2\ -2\not\equiv 0 \pmod{p^2}$ up to that limit.

6. *The Initial Motions of Electrified Spheres.* *By* J. W. Nicholson, *M.A., D.Sc.*

The problem of the initial motions of electrified spheres has been treated recently by G. W. Walker,[2] and the present paper consists mainly of an examination of some interesting cases, with corrections of detail. It discusses the motion of a sphere, conducting or dielectric, whose mass is purely of electrical origin, without a Newtonian element. For a conducting sphere of radius a and charge e, with electrical mass m' and small Newtonian mass m, starting from rest at $t=0$ in a uniform field F of electric force, the displacement of the centre at time t is

$$\xi=\frac{eF}{2m'}\left(t^2-\frac{2at}{c}+\frac{2}{3}\frac{a^2}{c^2}\right)-\frac{ea^2Fe^{\frac{-ct}{2a}}}{3m'c^2}\left\{\cos\frac{ct}{a}\left(\frac{m'}{m}\right)^{\frac{1}{2}}-\frac{5}{2}\left(\frac{m}{m'}\right)^{\frac{1}{2}}\sin\frac{ct}{a}\left(\frac{m'}{m}\right)^{\frac{1}{2}}\right\},$$

and the surface density is given by

$$4\pi\sigma=\frac{e}{a^2}+Fe^{\frac{-ct}{2a}}\cos\frac{ct}{a}\left(\frac{m'}{m}\right)^{\frac{1}{2}}\cos\theta.$$

The corresponding formulæ for a small mechanical force G are

$$\xi=\frac{G}{2m'}\left(t^2+\frac{2at}{c}+\frac{2a^2}{c^2}\right)-\frac{Ga^2e^{\frac{-ct}{2a}}}{m'c^2}\left\{\cos\frac{ct}{a}\left(\frac{m'}{m}\right)^{\frac{1}{2}}+\frac{3}{2}\left(\frac{m}{m'}\right)^{\frac{1}{2}}\sin\frac{ct}{a}\left(\frac{m'}{m}\right)^{\frac{1}{2}}\right\},$$

$$4\pi\sigma=\frac{e}{a^2}-\frac{3G}{e}\left\{1-e^{\frac{-ct}{2a}}\cos\frac{ct}{a}\left(\frac{m'}{m}\right)^{\frac{1}{2}}\right\}\cos\theta.$$

The difficulties connected with the limiting forms of these expressions when m is zero are discussed, and it appears impossible to ascribe an initial acceleration to the sphere without introducing imperfection in the conductivity, although the electrical distribution on the sphere tends to become uniform very rapidly. These results have a bearing on a possible conception of the electron.

The theory of the corresponding problem for an insulating sphere is also traced, and it is shown that these special difficulties are absent, and that a simple solution may be obtained when the dielectric constant is not small. The vibrations initially set up in this case have a much smaller rate of dissipation, but many possible periods instead of the single one belonging to the conductor.

A discussion of these periods and rates of decay is given for special values of the ratio m'/m. When this ratio is zero, or the sphere fixed or uncharged, the question has been treated by Lamb,[3] an additional period with a rapid rate of decay having since been indicated by Walker. The additional period is not present when $m=0$. For a rigid or uncharged sphere, the fundamental mode (ignoring the extra mode) is found to have a dissipation factor $e^{-\mu t}$ where $\mu=\frac{\rho^4}{\kappa^3}\frac{c}{a}$, $\rho=4{\cdot}493$.

When $m=0$, $\mu=\frac{\rho^2}{\kappa^2}\frac{c}{a}$.

For a value of $\kappa=5\,.\,10^6$, and a sphere of molecular size ($a=1{\cdot}3\,.\,10^{-8}$), as in Lamb's model of a molecule exhibiting selective absorption of light, the values of μ become respectively $1{\cdot}5$ and $1{\cdot}9\,.\,10^6$, so that, while the vibrations in the former case may be fairly permanent, those in the latter, for a sphere of the same size, and dielectric coefficient, will decay rapidly, and the dielectric sphere rapidly assumes a constant acceleration in a weak uniform field.

[1] *Comptes Rendus des Séances de l'Acad. des Sciences*, Paris, t. 83, p. 1288

[2] *Roy. Soc. Proc.*, A77, p. 260; *Phil. Trans.*, A 210, p. 145.

[3] *Camb. Phil. Trans.*, Stokes Commem. Volume.

7. *On the Need of a Non-Euclidean Bibliography.* *By* DUNCAN M. Y. SOMMERVILLE, *M.A., D.Sc.*

Thirty years ago Halsted published the first bibliography of non-euclidean Geometry and Hyperspace, and one still finds it referred to as a standard work. But the amount of literature published on the subject since that time is enormous, and the present yearly output would almost equal Halsted's whole collection. So, in spite of the excellence of this bibliography and the existence of others which have been more recently compiled, the student of non-euclidean geometry is pretty much in the same position as the student of any other branch of mathematics, and is confined for his sources to the volumes of the 'Jahrbuch,' the 'Revue Semestrielle,' and the 'International Catalogue.' A notable exception exists in the subject of Quaternions. In 1904 Macfarlane published an extensive bibliography of this subject, and the work is being continued by the International Association on a still broader basis. In many ways the two subjects are akin. The one is concerned with the foundations of geometry, the examination, modification, and extension of the geometrical ideas, and the investigation of all the various geometries which arise therefrom; the other is concerned with exactly analogous questions relating to arithmetic and algebras. As instances of the close connection which exists between their lines of development, one may mention finite geometries and galois fields, non-archimedean geometry and non-archimedean algebra. It is natural therefore to wish for the same facilities for the one department as exist for the other, but non-euclidean geometry is handicapped by having no International Association to promote its interests.

Several years ago the present writer started to collect material for a bibliography on the lines of Halsted's, but it soon became evident that the growth of the subject rendered such diffuse treatment practically impossible. Then in 1902 Bonola's catalogue appeared; but, though this is the most extensive bibliography that has yet been published, it still leaves something to be desired. It will be convenient to describe here the existing bibliographies and the present state of the material that has been collected. We may divide the subject roughly into three main branches: Theory of Parallels, Foundations of Geometry and Non-Euclidean Geometry, N Dimensions. Quite a number of bibliographies relating to the theory of parallels exist, dating mostly from the earlier portion of the nineteenth century, but they are all included in

1. P. Stäckel and F. Engel, 'Die Theorie der Parallellinien von Euklid bis auf Gauss,' Leipzig, 1895. Supplemented by a list in 'Bibliotheca Mathematica,' 1899.

A chronological list of works on the theory of parallels, including the early papers on non-euclidean geometry, from 1482 to 1837, with careful references to sources. Almost complete.

In the remaining divisions only three bibliographies need be mentioned.

2. G. B. Halsted, 'Bibliography of Hyperspace and Non-Euclidean Geometry,' 'Amer. Jour. Math.,' vols. i. and ii. (1878-79).

This is a general list, including both non-euclidean geometry and n dimensions from about 1830 to 1879. The order is mainly chronological, but all the works by the same author are collected together. Short notes are added to the chief works.

3. V. Schlegel, 'Sur le Développement et l'Etat Actuel de la Geométrie à n Dimensions,' 'Enseign. Math.,' vol. ii. (1900). First published in German in 'Leopoldina,' vol. xxii. (1886).

This includes only n dimensions up to 1897. The order is alphabetical under the authors. Letterpress of twenty pages contains an historical sketch corresponding to Halsted's notes.

4. R. Bonola, 'Index Operum ad Geometriam Absolutam Spectantium.' Published in 'Ioannis Bolyai, in Memoriam,' Klausenburg, 1902. First published in 'Boll. Bibliogr.,' Torino, 1899-1902.

A chronological list, not including n dimensions, from 1839 to 1902. A classification is attempted under a schedule of seven classes, with class-letters which are affixed to the titles. It is accompanied by an author-index. There is no subject-index, and the classification is not sufficiently detailed to be of much use.

The following table gives, for comparison, the number of titles in these bibliographies, and, in brackets, the number which the present writer has collected within the corresponding limits of time and subject-matter :—

	Th. of P. and N.-E. Geom.	N. Dim.
Stäckel and Engel	273 (330)	—
Halsted	112 (400)	76 (130)
Schlegel	—	439 (860)
Bonola	915 (1250)	—

The present writer's collection, which is made up to 1907 (the last year of the 'Jahrbuch'), contains about 3,500 titles, composed roughly as follows: Theory of parallels, 600; non-euclidean geometry and foundations of geometry, 1,300; n dimensions, 1,600. The arrangement of the material is in three parts, as in Riccardi's Euclidean Bibliography.

1. A chronological catalogue, the titles in each year being arranged alphabetically under the authors.
2. An author-index. This contains the full names of the authors with dates of birth and death, and the abbreviated titles with their dates. This index could be greatly condensed by giving only the dates of the papers, but a comparison of the 'Namenregister' of the 'Jahrbuch' with the 'Liste des Auteurs' of the 'Revue Semestrielle' shows the great advantage of the former system.
3. A subject-index. The classification used is that of the 'Index du Répertoire Bibliographique,' the new edition of which in 1908 was specially extended to treat adequately of hyperspace. The references here are by the author's name, the date and the number as 'Mansion 1896^8.' The class letters of this system are affixed to the titles in the chronological catalogue. It has been found advisable to classify somewhat more minutely than according to the headings of the 'Index'—for example, Q1b (hyperbolic geometry) is sub-divided according to the divisions of K^1 (elementary geometry), L^1 (conics), &c.

The foregoing considerations will show the scope, if not the demand, that exists for such a bibliography. The arguments for a new bibliography may be shortly summed up :—

1. The increasing importance and wide application of this branch of mathematics.
2. The convenience of having all the literature collected in one place, thus avoiding a prolonged search through a long series of volumes, and giving the literature of all time, whereas the periodicals, 'Jahrbuch,' &c., have a definite beginning.
3. The necessity for a subject-index (which none of the existing bibliographies possess), this being the most important and useful, as well as the most difficult, portion of the bibliography.

8. *Report on the History and Present State of the Theory of Integral Equations.* *By* H. BATEMAN.—See Reports, p. 345.

9. *The Foci of a Circle in Space and some Geometrical Theorems connected therewith.* *By* H. BATEMAN.

In a space of three dimensions the centres of the two spheres of zero radius (or isotropic cones) which pass through a circle have been called by Darboux the foci of the circle. Many focal properties of curves and surfaces may be studied with the aid of the foci of systems of circles—for instance, the foci of the circular sections of a conicoid lie on the focal conics, and conversely the circles whose foci are the extremities of a system of parallel chords of a conic generate a conicoid, and by varying the direction of the chords a confocal system of conicoids is obtained.

In a space of four dimensions the foci of a sphere may be defined to be the centres of the two hyperspheres of zero radius which pass through the

sphere. If two spheres lying in the same space of three dimensions touch, then the line joining a focus of one to one of the foci of the other is an isotropic line—*i.e.*, a line of zero length.

By considering the spheres which have the same kind of contact with two others and making use of the fact that the four points of contact lie on a circle we may deduce the following theorem: If the sides of a skew quadrilateral are isotropic lines they lie on a sphere.

In the same way we may prove that if the sides of skew hexagon in a space of five dimensions are isotropic lines, they lie on a spherical manifold of four dimensions. There is a similar theorem for a polygon of $2n$ sides in a space of $2n-1$ dimensions.

10. *On the Theory of the Ideals. By* Professor J. C. Field.

In the elements of the theory of the algebraic functions it is shown that the branches of an algebraic function v defined by an equation $F\ (z, v)=0$ as represented by a number of power-series in $z-a$ in the neighbourhood of a value $z=a$. These power-series have exponents integral or fractional, and group themselves into a number of cycles, the branches of these cycles having certain orders of coincidence with a given rational function $R(z,v)$. In his book on the algebraic functions the writer has defined these orders of coincidence as adjoint when they are equal to or greater than certain numbers

$$u_1 - 1 + \frac{1}{v_1} \quad . \; . \; . \; . \quad u_r - 1 + \frac{1}{v_r}$$

respectively, and has shown how to construct a rational function possessing any assigned set of adjoint orders of coincidence corresponding to the value of the variable in question. Hensel, in his book, 'Theorie der algebraischen Zahlen,' and also in two earlier Abhandlungen, which appeared in *Crelle's Journal* (Bde. 127, 128), has shown that an ordinary algebraic equation $f\ (x)=0$ is satisfied by certain series analogous to the well-known power-series referred to above. These series have reference to a prime p, and also group themselves in cycles like the more familiar series of the algbraic functions. On these series Hensel builds up a theory of the ideals. For a more precise description of the series here in question the reader is referred to the writings just cited.

In the present paper the writer, on starting out from Hensel's power-series, defines adjointness relatively to a prime p in a manner analogous to that in which he defines the property in connection with the algebraic functions. Employing the letter e to designate a solution of our algebraic equation, it is shown that we can construct a rational function $R(e)$ possessing any assigned set of adjoint orders of coincidence corresponding to a prime p. From this it readily follows that we can construct a rational function possessing any set of orders of coincidence with the branches of the cycles corresponding to the prime in question. We can then construct a general function $R(e)$ which represents only integral algebraic numbers and which possesses a single coincidence with the branches of an assigned one of the cycles corresponding to any prime, while it is not conditional with regard to any other specific prime or any other cycle corresponding to the prime in question. The aggregate of numbers represented by this function is a prime ideal.

11. *Report on Bessel Functions.*—See Reports, p. 37.

MONDAY, SEPTEMBER 5.

The following Papers were read :—

1. *Demonstration of Vacuum-tight Seals between Iron and Glass. By* Henry J. S. Sand, *Ph.D., D.Sc.*

Some cathode-ray tubes were shown in which a vacuum-tight seal between iron and glass has been obtained as follows : An iron wire is sealed into a glass

tube. While the glass is hot a small piece of heated steel tube surrounding the wire is pushed a few millimetres into the glass. After cooling the tube is soldered to the wire. The vacuum-tight seal is produced between the inner surface of the elastic steel tube, which on cooling is put under tension, and the glass which comes under compression. Seals with wires of 1 mm. diameter have been produced in this way.

2. *The Relation between Density and Refractive Index.* *By* Dr. T. H. Havelock.

3. *A Complete Apparatus for the Measurement of Sound.* *By* Professor Arthur Gordon Webster.

This research involves three parts, all necessary for the measurement of sound intensity in absolute measure. First, a constant source of harmonic vibrations, termed the *phone*; second, an instrument capable of measuring the intensity of the sound thus generated, and called a phonometer; third, the study of the propagation of the sound from the former and the latter, involving the determination of the reflecting power of the flat surface of the earth. The phone consists of a steel diaphragm rigidly driven by an electrically maintained tuning-fork, and made the back of a resonator, of the form of a small hollow chamber or of a tube of variable length. The reacting of the sound upon the amplitude of the fork enables the constants of the resonator to be accurately determined, so that the emission may be measured in watts. The phonometer is a glass diaphragm, made the base of a resonator of either type, and bearing a light mirror which constitutes one mirror of a Michelson interferometer. The displacement is measured stroboscopically by a moving telescope, and the amplitude of the pressure change is read off on a scale in dynes/cm^2. On account of the magnification due to resonance, the instrument is as sensitive as the ear for pitch 256 vibrations per second. The law of propagation is confirmed and the reflection of the earth determined by measuring at different distances from the phone the sound given by interference with its image in the ground. All points in the theory involved have been experimentally verified, and it seems possible to have an over-all accuracy of within 10 per cent.

4. *On the Relation of Spectra to the Periodic Series of the Elements.* *By* Professor W. M. Hicks, *D.Sc., F.R.S.*

The author described some results recently obtained by him in a critical study of the spectral series of the second and third groups of the periodic table of elements, more especially their dependence on the atomic volume of the element. Formulæ constants obtained from the wave numbers of three lines of the Sharp series are definite functions of atomic weight and atomic volume. The exact form of the function of atomic weight had not been yet determined, but when it is known the measurement of the wave-lengths of a spectrum should give one of the most accurate methods of determining the atomic weight of an element. The function of the atomic volume was so far determined as to give deductions of atomic volume, or of density, very close to observational values in the case of the first three groups of the periodic series. Applying the method to the spectrum of Europium as given by Exner and Haschek, a density of 13.1 was predicted for that element.

5. *The Series Spectrum of the Mercury Arc.* *By* S. R. Milner, *D.Sc.*

With the arc in air there is always a continuous background to the spectrum present. This sets a limit to the faintness of the lines which can be observed, since attempts to photograph faint lines by increasing the time of exposure will simply result in the fogging of the plate by the background. The spectrum of the arc *in vacuo* is characterised by an almost entire absence of a continuous

background, and exposures over one hundred times the normal can be given before the background makes itself evident. Photographs of the mercury arc *in vacuo* with very long exposures showed many new lines, among which the lines forming the continuation of the various series of mercury were strikingly developed. The wave-lengths of the lines of the principal and of the diffuse series have been measured up to the fifteenth, and those of the sharp series up to the thirteenth. The results afford a strict verification of Rydberg's law—that the frequency of the first line of the sharp series is equal to the difference of the limits of the sharp and the principal series.

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6. *On Apparatus for the production of Circularly Polarised Light and a New Form of White Light Half-shade.* *By* A. F. Oxley.

If we send a beam of plane polarised light through a Fresnel's rhomb—the azimuth of the incident vibration being 45° with respect to a principal section of the rhomb—the emergent beam of circularly polarised light is displaced laterally from the incident beam. This necessitates readjustment of the successive pieces of apparatus if we are to keep the beam of light in the field of view as the rhomb is rotated. If we use a quarter-wave plate to produce the circularly polarised light no lateral displacement is experienced, but we are limited to the use of monochromatic light in this case. The idea of the present investigation was to devise a piece of apparatus which would produce a beam of circularly polarised white light without involving the inconvenience of the lateral displacement previously referred to.

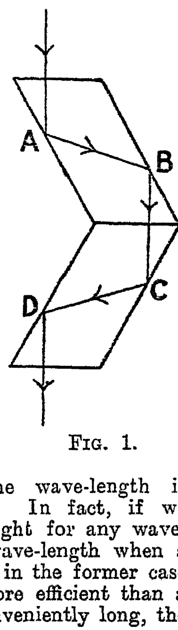

Fig. 1.

Two pieces of apparatus have been devised with this object in view. In the first, two rhombs of glass are arranged as shown in fig. 1, the rhombs being in close contact. A beam of plane polarised light enters at the top and is reflected in turn from the surfaces A, B, C and D, so that the direction of the energent beam is a continuation of that of the incident beam. If the refractive index of the glass be 1·5035 for D (Uviol glass) and the angle of the rhomb be 74° 38′·2, the phase difference between the component vibrations polarised parallel and perpendicular to the plane of incidence is equivalent to $\frac{\pi}{2}$, and the emergent light is consequently circularly polarised. If the angle of the rhomb be 42° 34′·8, we still get the same effect; but since the variation of the phase difference between the components with respect to the wave-length is much smaller for the larger angle, the latter is adopted. In fact, if we choose the larger angle, the ellipticity of the transmitted light for any wave-length is over half the ellipticity for the corresponding wave-length when a Fresnel's rhomb is used, although there are four reflections in the former case and only two in the latter. Hence the present form is more efficient than a Fresnel's rhomb; but it has the disadvantage of being inconveniently long, the length being 15 cm. for an aperture of 1·1 cm.

This difficulty has, however, been overcome to a large extent in the second

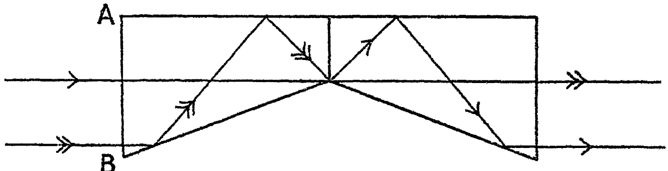

Fig. 2.

form of polariser, in which three reflections are used. Fig. 2 shows the path of a beam of light through the apparatus. The two blocks of glass are pressed

together and the beam of light passes obliquely across the joint. The angle of the glass is obtained from a rather complicated equation by trial and error, and found to be 73° 48′·6 (Uviol glass). The efficiency of this form is a little greater than that of a Fresnel's rhomb, and, moreover, its length is 7·5 cm.

Since the component polarised in the plane of incidence is more copiously reflected on crossing the joint than the perpendicular component is, it is necessary to adjust the azimuth of the incident vibration to compensate for this. The correct azimuth with respect to the line AB is Ω where

$$tan\ \Omega = \frac{1}{cos^2(\phi - \psi)}$$

where ϕ is the angle of incidence of the beam on the glass-air surface and ψ the corresponding angle of refraction. For $\mu\, D_1 = 1{\cdot}5035, \Omega = 49° 2'$.

In the British Association Reports for 1851 Professor Stokes described a new elliptic analyser consisting of a plate of selenite which retarded waves of mean refrangibility by about a quarter of a wave-length. Some experience is required in its use, since we are to work by intensity, and the tint produced perplexes the experimenter. Still, Professor Stokes claimed very good results to be obtainable by his apparatus. As it is difficult to make accurate settings of a quarter-wave plate and analysing Nicol, I thought it probable that the second form of polariser, mounted[1] so as to be capable of accurate setting, may prove useful in the analysis of elliptic vibrations.

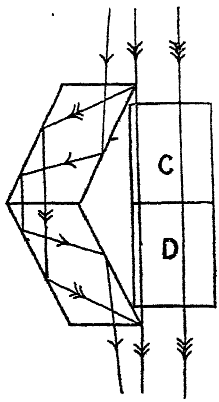

FIG. 3.

On a New Form of White Light Half-shade.

The arrangement of the rhombs in the first form, described above, may be used to form a white light half-plate. Taking $MD^1 = 1{\cdot}5173$, and the angle of each rhomb 55° 15′·5, the total phase difference between the components on emergence is π. Half the field of view is occupied by the aperture of one of these rhombs and the other half by the end of one of the glass blocks, C, D. These blocks partly compensate for absorption, but their chief use is to compensate for the loss of light at the four reflections at normal incidence. This half-shade—using white light—has been compared with the Laurent half-shade—using monochromatic light—and was found quite as efficient as the Laurent. Since the cost of large blocks of calcite is becoming more and more prohibitive to their use, the present form of white light half-shade, which can readily be made by mounting the rhombs as indicated, may prove useful. The length for an aperture of 1·6 cm. is about 3 cm.

Joint Discussion with Section G on the Principles of Mechanical Flight. Opened by Professor G. H. BRYAN, *F.R.S.*

TUESDAY, SEPTEMBER 6.

Discussion on Atmospheric Electricity. Opened by Dr. CHARLES CHREE, *F.R.S.*

Atmospheric electricity includes a great variety of phenomena. Omitting Aurora as a subject so large as to require a separate discussion, we may mention the potential gradient in the atmosphere, the influence of potential gradient and electrical charges on the growth of vegetation, the phenomena of thunderstorms, the loss of charge experienced by insulated bodies, the number and

[1] The edge of the glass which replaces an axis of the quarter-wave plate should be specially worked.

nature of the positive and negative ions in the air, the vertical earth-air current, and the phenomena of radioactivity. The potential gradient and its diurnal and annual variation have been the subject of study for a good many years, and we know that the phenomena vary largely with the season of the year at any given station, and that there are notable differences between different stations at ground-level. As yet but little is known of the diurnal and annual changes at different heights in the free atmosphere. Observations made near the top of the Eiffel Tower suggest that the phenomena alter rapidly as the height above the ground increases. Thus observations from balloons and kites, if these could be maintained at a fixed level, would be of great importance. The influence of electricity on the growth of plants, first seriously studied by Professor Lemstrom, seems not unlikely to prove in the future of economic importance. The phenomena of thunderstorms have received considerable study from meteorologists, but many lines of investigation present themselves. The loss of charge of insulated bodies and the ionic charges in the atmosphere have been most studied in Austria and Germany, Elster and Geitel in particular having done much pioneer work. In this country Mr. C. T. R. Wilson has investigated the electric charge brought down by rain and has invented an instrument for measuring the earth-air current. While a great number of theories have been advanced to account for the several phenomena, there are few, if any, of them which command anything like universal acceptance.

Department of Mathematics and Physics.

The following Papers and Report were read :—

1. *An Auto-collimating and Focussing Prism, and a Simple Form of Spectrograph. By* Professor C. Féry, *D.Sc.*

The value of the spectroscope, and especially of the quartz spectrograph, which includes the ultra-violet rays, as a means of scientific research, has led the author to attempt the simplification of the apparatus to render it suitable for industrial investigations concerning metals, alloys, &c. The employment of the principle of auto-collimation, with a 30° prism, simultaneously shortens the apparatus, simplifies the lens system, and avoids trouble due to the rotatory properties of the quartz, since the prism is traversed twice in opposite directions. But the difficulty still remains with the ordinary lens system, that the non-achromatism of the lens leads to a somewhat impure spectrum, and to a very great inclination (about 64°) of the plate. Hence a means was sought of eliminating this lens. The general condition for producing a pure spectrum is that all the incident or refracted rays should make the same angle with the refracting surface. By giving suitable spherical curvatures to the front and back surfaces of the prism this condition is very closely realised, and a sharp spectrum is obtained on a cylindrical surface, exactly as with a curved reflecting grating, and with a much smaller inclination of the plate.

The spectrograph therefore consists simply of a heavy base, upon which is fixed the new prism, a carefully made slit, and a slide for holding the plates and bending them to the required cylindrical form, and also permitting of a vertical displacement of the plate, so as to get several successive spectra in exact juxtaposition for easy comparison. The adjustments can be made and clamped, and a light-tight cover slipped into grooves, leaving only the slit and the back of the slide exposed. A quartz cylindrical lens is fixed on a sliding rod, so that its optic axis is always coincident with that of the slit and prism, and serves to concentrate the light from the arc or other source on the slit. The exposure for an arc spectrum under normal conditions is about thirty seconds.

The author described the theory of the prism and the details of the apparatus, and also gave examples of the photographs obtained.[1]

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[1] See *Engineering*, October 7, 1910.

2. *The Magnetic Field produced by the Motion of a Charged Condenser through Space.* *By* W. F. G. Swann, *B.Sc.*

After referring to the impossibility of detecting the magnetic field by means of a compass needle, the possibility of detecting it by means of a rotating coil was discussed. It was first shown that in the case of a closed circuit at constant potential moving through space in company with a system of charged bodies, the total magnetic flux through the circuit is zero. If, however, the space within the coil is partially filled with a dielectric, then, provided that the S.I.C. may be looked upon as a quantity absolutely continuous throughout the dielectric, a magnetic flux through the coil should exist; it was shown further, however, that if dielectric action is to be explained entirely by the presence of electric charges, or doublets, no resultant magnetic flux is to be anticipated, even in this case.

Two condensers were formed from three parallel plates, the middle plate being common to both condensers. Two coils fastened to the same axle, and wound in opposite directions so as to eliminate fluctuation of the earth's field, were rotated, one between the plates of each condenser. The apparatus gave a null effect, which is taken to support the doublet theory of dielectric action.

3. *On the Secondary Radiation from Carbon at Low Temperatures.* *By* V. E. Pound.

In this paper a series of experiments were described, in which measurements were made on the secondary rays from carbon in air when bombarded in a high vacuum by the Alpha rays from polonium.

Observations were made (1) at room temperature and (2) at the temperature of liquid air. The secondary radiation excited at the lower temperature was found to be about 50 per cent. greater than that obtained at the higher temperature, and this marked difference was ascribed to the presence of the large quantity of air which is known to be occluded in the carbon. The same phenomenon was observed when hydrogen was occluded in the carbon instead of air.

4. *Photoelectric Fatigue.* *By* H. Stanley Allen, *M.A., D.Sc.*

The observation of Hertz in 1887 that the electric spark passes more readily when the spark gap is illuminated by ultra-violet light led to the discovery by Hallwachs of the photoelectric current. A negatively charged body often loses its charge rapidly when exposed to light, especially to ultra-violet light. The discharge is due to the emission of negative electrons from the illuminated surface. The photoelectric activity of a freshly polished metal surface diminishes with the time, falling off rapidly at first, more slowly later on. This is known as the 'fatigue' of the Hallwachs effect. In the early literature of the subject the fatigue was attributed to the direct action of the light, but Hallwachs showed in 1904 that fatigue proceeds in complete darkness, so that light cannot be the primary cause of the change. This result has been questioned, but is now confirmed by the experiments of Bergwitz. Dember, Ullmann, and Allen. Light can, however, set up secondary actions tending to accelerate or retard fatigue.

Hallwachs has shown that at ordinary pressures fatigue is more rapid in a large vessel than in a small one. This also was called in question by Aigner, but is confirmed by Ullmann and by Allen.

The fatigue is practically independent of the electrical condition of the plate. This was shown by v. Schweidler and has received confirmation in the researches of Hallwachs, Sadzewicz, and Allen.

Experiments in a vacuum have led to contradictory results. Lenard and Ladenburg found marked fatigue in certain cases, while for the alkali metals, first investigated by Elster and Geitel, several observers conclude that there is

no true fatigue. Recent experiments by Millikan and Winchester show no fatigue with clean unpolished metal surfaces in a very high vacuum. To explain the fatigue found by other investigators we must take into account the mode of preparation of the surface (Ladenburg's plates were polished with emery and oil), the difficulty of removing air films from the surface, and the possibility of changes in the gas pressure.

Various theories have been advanced as to the nature of the change accompanying photoelectric fatigue :—

(1) A chemical change, such as oxidation of the surface.

(2) A physical change of the metal itself, as, for example, a roughening of the surface.

(3) An electrical change in the formation of an electrical double layer (Lenard).

(4) A disintegration of the metal, due to the expulsion of electrons by light (Ramsay and Spencer).

(5) A change in the surface film of gas or in the gas occluded in the metal (Hallwachs).

Hallwachs has shown from the photoelectric behaviour of copper and its oxides that oxidation cannot be the cause of fatigue, and the fact that fatigue is less in a small vessel may be interpreted by attributing it to some substance (*e.g.*, ozone, water vapour) present in small quantities in the surrounding atmosphere. The results recorded lead to the view that the main cause of fatigue is to be found in the condition of the gaseous layer at the surface of the plate.

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M. Hoor (' Akad. Wiss. Wien. Ber.' 97, p. 719), ' Einfluss des Lichtes auf negativ geladene Konduktoren.'

W. Hallwachs (Phil. Mag. (5) 26, p. 78), ' On the electrification of metal plates by irradiation with electrical light.'

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M. Hoor (' Exner Rep.' 25, p. 91), ' Einfluss des Lichtes auf negativ geladene Konduktoren.'

A. Stoletow (' C. R.' 108, p. 1241), ' Sur les phénomènes actino-électriques.'

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5. *On the Recoil of Radium B from Radium A.* *By* Dr. W. Makower, Dr. S. Russ, *and* E. J. Evans.

The first experiments by Russ and Makower were made to determine whether RaB is electrically charged when it recoils *in vacuo* from RaA, and, if so, the sign and magnitude of the deflection. A number of experiments, in which the RaB was passed through a strong electric field maintained between two brass electrodes made it clear that RaB is positively charged in these circumstances. Further experiments were therefore made, in which RaB recoiling *in vacuo* from a wire coated with RaA was caused to pass between two brass plates, 1·17 mm. apart, kept at a difference of potential which varied in different experiments from about 1,000 volts to 2,000 volts. The RaB subsequently fell upon a brass strip. After an exposure of ten minutes to the radiation the brass strip was removed, and the distribution of activity over the strip was tested by mounting it on a movable platform and bringing successive portions of the strip under a rectangular window made of aluminium leaf cut in a sheet of lead forming the base of an α-ray electroscope. The window was 3 mm. long and 1 mm. wide. The magnitude of the deflection thus found was of the order of magnitude to be expected if RaB carries the atomic charge of electricity and if its atomic weight is 214, as is to be expected on the transformation theory of radio-active processes.

Experiments were also made by Makower and Evans on the magnetic deflection of RaB when it recoils. The radiant matter was made to pass *in vacuo* through the field of a powerful electro-magnet, and then to fall upon a brass

strip as in the experiments on the electric deflection. The distribution of activity over the strip was measured and the magnitude of the deflection produced by the magnetic field thus determined.

By measuring the radius of curvature of the radiation in a magnetic field of known strength the value

$$\frac{mv}{e} = 7{\cdot}26 \times 10^5$$

was obtained.

In later experiments the RaB recoiling from a platinum wire coated with RaA was allowed to pass, in a magnetic field, through a slit and then fall upon a brass strip for three minutes. The magnetic field was then reversed and the radiation allowed to continue for seven minutes, until the RaA on the wire had decayed to an inappreciable quantity. The brass strip was then removed and placed on a photographic plate and left for several hours. The RaC formed *in situ* from the RaB on the strip produced an impression on the photographic plate when developed. It was found that there were two well-marked maxima of intensity, representing the distribution of RaB reaching the strip with the direct and reversed magnetic fields. By measuring the distance between these maxima, and from the known dimensions of the apparatus, the radius of curvature of the rays in a magnetic field of known strength was determined, giving the value

$$\frac{mv}{e} = 6{\cdot}52 \times 10^5$$

This value is in fair agreement with that obtained by the first method and is probably somewhat more accurate.

The value of $\frac{mv}{e}$ for the α particle from RaA has been found by Rutherford to be $3{\cdot}4 \times 10^5$. Now, since the momentum of the α particle and that of the recoiling atom must be the same, it follows from these numbers that RaB carries the atomic charge of electricity, since the α particle carries twice that charge.

Taken in conjunction with the results of the experiments on the electrostatic deflection, the velocity of the radium B particles is found to be $3{\cdot}23 \times 10^7$ cm. per second and its atomic weight 194.

6. *On the Resolution of the Spectral Lines of Mercury.* *By* Professor J. C. McLennan *and* N. Macallum.

In this communication a series of slides were exhibited which illustrated the resolving power of a high-grade echelon spectroscope recently made by the Adam Hilger Co. for the Physical Laboratory at Toronto. With this instrument the green line of mercury 5461 AU was shown to consist of a central doublet accompanied by three satellites of greater and by three of smaller wave-length, and the blue line 4389 AU to consist of a central strong line accompanied by three satellites of greater wave-length and by two of shorter wave-length. The results are in good agreement with the components of the same lines recently obtained by Gale and others with a 7-in. Michelson plane grating.

Slides were also shown which illustrated the magnetic resolution of the satellite of shortest wave-length of the line 5461 AU. Under magnetic fields of 2,000 Gauss this line was resolved into a quartet, the inner doublet of which corresponded to vibrations parallel to the magnetic field and the outer to vibrations perpendicular to the magnetic field. Measurements made on the displacements of the lines constituting the quartet showed that the magnetic separation of the two doublets corresponded approximately to three fourths and three halves that of the outer components of a normal triplet.

7. *On the Active Deposit from Actinium.* *By* W. T. Kennedy.

This paper was presented by Professor McLennan, and contained an account of experiments made on the active deposit obtained when the emanation from actinium was allowed to diffuse freely between two parallel plates placed about

two millimetres apart, directly over the actinium salt. These two plates were maintained at a difference of potential of about 250 volts.

Measurements were made on the amount of the active deposit obtained at different pressures on a narrow strip of the negatively charged plate, at a distance x from the salt. The deposit was found (with different values selected for x) to reach a maximum at a certain critical pressure which varied according to the law $p.x$=a constant. From the fact that the maximum deposit followed this law, it was concluded that the amount of active deposit corresponding to a given constant amount of emanation under equilibrium conditions which possessed a positive charge varied with the pressure of the gas in the emanation chamber.

The expression $I = \frac{I}{p^{\frac{1}{2}}\epsilon^{c}/p^{\frac{1}{2}}}$ was deduced for the amount of active deposit possessing a positive charge under these conditions. It was also pointed out that these experiments seemed to show that the deposit particles acquired their positive charges from the surrounding ionised gas by a process of diffusion rather than as a direct result of the expulsion of alpha particles accompanied by electrons in the process of disintegration.

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8. *Report of the Committee on Electrical Standards.*—See Reports, p. 38.

Department of Cosmical Physics and Astronomy.

The following Papers were read :—

1. *On Barometric Waves of Short Period.* *By* Dr. Wilhelm Schmidt.

To carry out an investigation of barometric waves of short period it is essential to eliminate the changes of longer duration as far as possible. In the variograph a recording instrument with this air was shown. It registers, instead of the *barometric pressure* at every moment, the *rate of its variation—i.e.*, its *first differential coefficient in regard to the time.* A uniform rise in barometric pressure of $\frac{1}{100}$ of a mm. mercury per second, for instance, is in this instrument recorded by a constant deflection of the recording pen of 1 to 3 cm. from the zero-line.[1]

A good place for researches of this sort was found at Innsbruck, in the Tyrol. Here, especially in winter time, exist all the conditions necessary for the formation of a cold-air lake at the bottom of the valley, whereas above it there is often a warm, dry, southerly wind, the 'foehn.' By its influence waves are generated in the separating surface and recorded at the bottom as barometric oscillations, the pressure being higher under the crest of a wave, lower under its valley.

Samples of records were shown, obtained at two points, 1,950 metres apart. They led to the conclusion that waves of longer duration are probably standing waves, while those of shorter period are propagating ones. In a certain case of foehn, where movement and temperature of both layers could be deduced from observations, a comparison with the theory was tried.

The formula of Helmholtz gives for the duration of a single oscillation a value between 3 min. 17 sec. and 3 min. 19 sec. if one takes into account the current of the foehn only—a minimum value of 3·6 min. with the observed westerly wind at the bottom. Both sorts of waves are independent of one another, and, if formed, there will be only a sort of interference on the variograph curves. The observed period was 3·5 min., which is in very good agreement with the theory. Standing waves would also be possible, due to transversal oscillations in the cold-air lake, but with a probable duration of 9 min. about.

As the conditions here are very favourable, regular waves of pressure were found very often in the mountain-valley. But they occurred also at a place with much freer exposure, at Vienna. Here they could not be so dependent upon local conditions, but must show the influence of the general conditions

[1] The instrument is fully described in *Wiener Sitzungsberichte*, June 1909.

in the free atmosphere. Three causes of very regular waves were shown, two occurring during or instantly after a rapid increase of pressure, the third during a more constant, but somewhat irregular, rise. The variogram of a more complicated line-squall consisted also of rather regular waves.

In all those cases in which one had pronounced regular oscillations, some hours after their occurrence a line-squall was observed; and, *vice versa*, in most cases of stronger squalls regular waves of pressure were developed some time before. Such oscillations may therefore be due to some disturbance on the front of secondary or V-shaped depressions, in whose rear cold air is flowing in. This suggestion is confirmed also by cloud observations.

The study of the minor fluctuations of the atmosphere, and especiallv of regular waves, may therefore be not only of purely theoretical interest, but also useful in forecasts as an indication of changes in the free atmosphere.

2. *Observations on the Upper Atmosphere during the Passage of the Earth through the Tail of Halley's Comet. By* W. H. Dines, *F.R.S.*

This paper gave the results obtained from thirteen ascents of registering balloons from Ditcham Park, Pyrton Hill, and Manchester. The records do not show any result that can reasonably be put down to the action of the comet, but they nearly all agree in showing that at that particular time rapid variations of temperature were in progress in the upper air. It was pointed out that an unusual number of oscillations were recorded on the microbarograph during that week, and the possibility of the two phenomena being connected was discussed, and the difficulty of finding any reasonable explanation of the large changes of temperature that are known to occur in the upper atmosphere was pointed out.

3. *Radiation Pressure in Cosmical Problems. By* J. W. Nicholson, *M.A., D.Sc.*

The paper dealt mainly with a determination of the pressure produced by a train of plane electromagnetic waves incident on a totally reflecting sphere. This problem has been worked out previously by Schwarzschild,[1] but more extended calculations do not support his numerical results in detail. Yet the general character of the results is preserved. When the incident light is monochromatic, the following table may be constructed, where p is the pressure, a the radius of the sphere, and λ the wave-length :—

$\frac{2\pi a}{\lambda}$	0·5	0·6	0·7	0·8	0·9	1·0
$\frac{\lambda}{2a}$	6·28	5·24	4·49	3·93	3·49	3·14
$\frac{p}{\pi a^2 E}$	0·29055	0·58133	1·0245	1·5561	2·0648	2·41945
$\frac{2\pi a}{\lambda}$	1·1	1·2	1·5	2·0	2·5	3·0
$\frac{\lambda}{2a}$	2·86	2·62	2·09	1·57	1·26	1·05
$\frac{p}{\pi a^2 E}$	2·8564	2·5254	1·9978	1·5893	1·4415	1·320

[1] *Sitz. der Math. Phys. zu München,* 1901-02, p. 293.

The incident energy per unit volume is E, and the limiting pressure on a large sphere is $\pi a^2 E$. Schwarzschild gave 2·5 as the maximum ratio of pressure to $\pi a^2 E$, but the true value is between 2·9 and 3. For a tail of a comet composed of particles of the proper density, this increases the maximum possible ratio of pressure to gravitational attraction of the sun from 18·5 to 22 for monochromatic rediation.

When the ratio of diameter to wave-length increases beyond the critical value corresponding to this maximum, the fall of the ratio $p/\pi a^2 E$ towards unity is less rapid than Schwarzchild's figures would indicate, so that there is a closer approximation to the maximum, for a given size of particle, over a greater range of the spectrum.

When, by the use of Wien's law, the effect of the continuous spectrum on any particle is determined, the maximum pressure is larger, for two reasons—viz., the increase in the monochromatic maximum and the decrease in its gradient—than that hitherto accepted. The increase is very useful to a radiation pressure theory of the tails of comets in that it removes the necessity for the majority of the particles in these tails to be totally reflecting, and at the same time approximately of the critical size.

When two particles fairly close together are under the influence of solar radiation, they will mutually repel in certain cases, and the size for which the mutual repulsion will just balance the gravitational action will be much larger than in the case dealt with above. A mathematical determination of this critical size would be of great service in testing an alternative theory of the tails, and appears to be possible. The need for work on these and other lines was emphasised in the paper.

A departure from the spherical shape could greatly increase the maximum pressure in some cases, and that of a disc-shaped particle provides a rough illustration.

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4. *Note on the Results of the Hourly Balloon Ascents made from the Meteorological Department of the Manchester University, March* 18 *to* 19, 1910. *By* Miss Margaret White, *M.Sc.*

The balloons carried Dines self-recording instruments, and were sent up hourly from 7 p.m., March 18, to 10 p.m., March 19. Twenty were recovered.

A north wind prevailed at the ground during the greater part of the period over which the ascents extended, but it became more westerly in the afternoon of the 19th. The balloons were found in the Hereford, Worcester, and Monmouth districts, one reaching North Devon.

While the maximum height reached varied from 9 to 20 kms., the direction of the places of fall was constant within 18°, and this slight change was progressive and in the same direction as the variation in the direction of start. It thus appears that the direction of the upper wind was constant throughout the time of the experiments and did not vary with height. The direction followed was practically that of the isobars shown at the ground.

The maximum duration of the ascent (obtained from information of the time at which the balloons were picked up or, in some cases, seen falling) in several cases did not exceed two hours, which, assuming a uniform increase of wind velocity with height, indicates a maximum velocity of more than 100 miles per hour. A table giving the direction of start, maximum height reached, and distance in direction of place of fall was shown.

The curves of variation of temperature with height were given. These do not diverge from the now well-known general type. The average temperature gradients shown for successive kilometres above sea-level are : 0·97, 0·41, 0·41, 0·47, 0·54, 0·58, 0·69, 0·70, 0·63, 0·58, 0·21, −0·11, −0·12, −0·11, −0·08, −0·03, −0·02, −0·01, −0·02, −0·05 degrees Centigrade per 100 metres.

Isothermal lines over the time of the ascent are plotted at intervals of 5° C. Whereas at the ground level the temperature was remarkably constant throughout the course of the experiments, showing a variation of less than 2° from the mean, the isothermals at the higher levels show a well-marked rise throughout the first fifteen hours,—*e.g.*, a temperature of −40° C. was at first encountered at a height of six kilometres, and at the end of twelve hours was not met with

until eight kilometres was reached. In fact the isothermals at the higher levels follow the general trend of the ground barometer, but the results are scarcely sufficient definitely to regard this as more than a coincidence.

The effect of solar radiation during the daylight hours on the temperature of the upper layers was almost inappreciable in this series and also in the series June 2 and 3, 1909.

The curves show that there was no very considerable absorption in any one layer, and it may be calculated numerically that the maximum effect of the sun's rays during a March day would only be sufficient to raise the temperature of the whole thickness of the atmosphere by a few degrees Centigrade.

5. *Temperature Inversions in the Rocky Mountains.* *By* R. F. Stupart.

6. *The Effect of Radiation on the Height and Temperature of the Advective Region.* *By* E. Gold, *M.A.*

If H_c denote the height and T_c the temperature of the layer at which the advective region begins, then observations show (1) that H_c is greater and T_c less over anticyclones than over cyclones; (2) that H_c increases and T_c probably decreases with approach towards the equator. While the conditions (1) are temporary in character and may be not due to but in spite of radiation effects; (2) represents an approximately steady and permanent state in which radiation must play a predominant part. The following conclusions have been reached by the use of the methods developed in 'The Isothermal Layer of the Atmosphere and Atmospheric Radiation.'

If the atmosphere be divided into two regions, in the upper of which the temperature is constant, then for a given temperature distribution from the earth's surface upwards, the excess of the radiation from the upper layer over the absorption by it of terrestrial radiation, *i.e.*, radiation from earth and lower atmosphere, increases if the absorbing power, b, increases (a) in the upper region alone, (β) in the convective region alone, (γ) throughout the atmosphere. This means that so far as radiation from terrestrial sources is concerned an increase in the absorbing power of the atmosphere will bring about a decrease in the temperature T_c and an increase in the height H_c of the advective region, provided the temperature in the convective region remains unchanged.

If the value of b remains invariable while the temperature in the convective region increases, the values both of H_c and of T_c increase also.

It appears therefore that we have here the basis of the explanation of the variation with latitude. The increase in humidity towards the equator means an increase in b at least in the lower part of the atmosphere, and therefore an increase in H_c, a decrease in T_c. The increase in temperature, however, means an increase both in H_c and in T_c. Thus the two effects reinforce each other so far as H_c is concerned, while for T_c they are opposed. The results of observation are on the whole in accordance with this. The change in H_c is very marked, that in T_c is slight.

There is, however, another condition to be satisfied. The total radiation out to space from the earth and atmosphere must balance the total absorption of solar radiation by earth and atmosphere so long as the temperature of the earth remains nearly constant. The exact distribution in latitude of the absorption is not known, but it is certainly greatest at the equator and diminishes towards the poles. The radiation must then also be greatest near the equator and must diminish pole-wards, but the rate of variation with latitude will be smaller than for the absorption owing to the transference of energy by oceanic and atmospheric currents.

Now if the atmosphere is what is termed a 'gray' body, *i.e.*, if each layer of it radiates throughout the spectrum with an intensity proportional to that of a black body at the same temperature, any increase in b diminishes the value of the outward radiation, and if the diminution is great enough to counterbalance the effect of an increased surface temperature on T_c, it will also counterbalance the effect of the increased temperature on the outward radiation. There could not therefore under these circumstances be a balance in the transference of energy since the outward radiation would be at least as small near the equator as in higher latitudes. Thus the atmosphere cannot be regarded as a 'gray body' in strict calculations on the

connection between radiation and the advective region. Of course it is known experimentally that the absorption of the atmosphere for different wave-lengths does vary very much, but it seemed possible that an average value would be sufficiently accurate for practical applications. This proves now not to be the case, and calculations based on the assumption that it is permissible may be subject to large corrections.

There must be a considerable portion of the spectrum for which the atmosphere is nearly transparent, and it is this fact which makes possible a lower temperature in the advective region near the equator. If this were not the case, the temperature at the earth's surface and in the convective region would rise until the balance with the absorbed solar radiation was established, which could only be after the temperature of the advective region had risen above its value for temperate latitudes.

It has been suggested that the cause of the variation of T_c with latitude is a greater proportion of ozone in temperate than in equatorial regions in the upper atmosphere. This is in itself insufficient, because T_c depends not on the absorbing power of the advective region but upon the 'effective' temperature of the incident radiation. If the latter is unchanged, an increase in absorption in the advective region is accompanied by an increase in radiation from it and there is no increase in T_c. The distribution of ozone may modify the conditions in proportion to its relative importance as an absorbing constituent, compared with water vapour. It could affect T_c in the manner observed only (1) if water vapour were transparent to ozone radiation; (2) if the intermediate atmospheric layers were nearly transparent to ozone radiation; (3) if ozone predominated in the advective region in temperate latitudes and water vapour in the same region near the equator.

If, as is generally accepted, the vertical motion near the equator is upwards only, then for all heights above the condensation level, 2 km. say, the air must be saturated with water vapour. Thus if the vertical temperature gradient is the same as for a place in the temperature zone in latitude ϕ, the amount of water vapour between the isothermal surfaces at temperatures t_0, t_c must be greater near the equator than in latitude ϕ, t_0 being the surface temperature and t_c that of the advective region in latitude ϕ. But the outward radiation across the surface, t_0, is greater at the equator than in latitude ϕ, owing to the higher temperature of the air beneath the surface. There must then be more of this radiation absorbed unless the value of T_c at the equator is to exceed t_c; and this greater absorption is in accordance with the deduction regarding the water vapour made above. We may say therefore that the variation in the distribution of water vapour, combined with the presence of spectral regions for which the atmosphere is nearly transparent, is alone sufficient to explain the variation of T_c and H_c with latitude.

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7. *A Sensitive Bifilar Seismograph with some Records.* *By* Professor F. G. Baily, *M.A.*

WEDNESDAY, SEPTEMBER 7.

The following Papers and Reports were read :—

1. *Stars as Furnaces.* *By* Sir Norman Lockyer, *K.C.B., F.R.S.*

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2. *On the Evolutions of a Vortex.* *By* Professor W. M. Hicks, *F.R.S.*

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3. *Report of the Seismological Committee.*—See Reports, p. 44.

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4. *On the Rate of Propagation of Magnetic Disturbances.* *By* C. Chree, *D.Sc., F.R.S.*

This paper was mainly devoted to a recent view of Dr. L. A. Bauer, head of the Department of Terrestrial Magnetism in the Carnegie Institution of

Washington, and editor of 'Terrestrial Magnetism,' who believes he has established the fact that the so-called 'sudden commencements' of magnetic storms are propagated at such a rate as to take on the average about $3\frac{3}{4}$ min. to go round the earth. Dr. Bauer believes the cause of these disturbances to be a peculiar form of overhead electric current in the plane of the earth's equator, due to charged ions whose height is on the average about fifty miles. Dr. Bauer advances a theory to account for the motion of the charged ions, which the author criticised. The conclusion reached is that the theory is unsatisfactory in several respects. The paper also dealt with a recent paper by Mr. R. L. Faris which treats of the records of fifteen magnetic disturbances as recorded at the five stations of the U.S. Coast and Geodetic Survey, viz., Porto Rico, Cheltenham (Maryland), Baldwin, Sitka, and Honolulu. Mr. Faris deduces from the observed times of commencement of the disturbances finite rates of propagation whose average seems to accord well with Dr. Bauer's theoretical conclusions. The data given by Mr. Faris was regarded critically from several points of view, and a variety of apparent inconsistencies pointed out.

The final conclusion reached is that the evidence advanced by Mr. Faris is inconclusive.

5. *Ninth Report on the Investigation of the Upper Atmosphere.*
See Reports, p. 72.

6. *Report on Magnetic Observations at Falmouth Observatory.*
See Reports, p. 74.

7. *Report of the Committee to aid in Establishing a Solar Observatory in Australia.*—See Reports, p. 42.

8. *Report on the Geodetic Arc in Africa.*—See Reports, p. 75.

9. *Report on the Provision for the Study of Astronomy, Meteorology, and Geophysics in the Universities of the British Empire.*—See Reports, p. 77.

Section B.—CHEMISTRY.

President of the Section.—J. E. Stead, F.R.S., F.I.C., F.C.S.

THURSDAY, SEPTEMBER 1.

The President delivered the following Address:—

[Plates viii.-xi.]

It was with considerable diffidence that I accepted the position of President of this Section. The long list of illustrious and eminent chemists who have occupied the chair in the past, scientists of the highest attainments, and usually professors of our educational institutions, is indicative of the very high standard to be followed. As, however, it was urged that a President with experience in the metallurgy of iron and steel was desired, I bowed to the decision of the Council, concluding that even as a mere layman I might, in this address, discuss one or more subjects to which prominent metallurgists have for the past thirty years directed their earnest attention, both in Europe and America. I refer to some of the underlying phenomena connected with the effect of sulphur and silicon on the carbon condition of commercial cast iron.

The effect of sulphur and silicon on cast iron has received the attention of Karsten, Percy, Weston, Howe, Keep, West, Dillner, Bachman, Summershach, Wüst, Johnson, Stoughton, Hailstone, Longmuir, Adamson, Turner and Schuler, Levy, and many others. They all agree in concluding that sulphur tends to make iron white by retaining the carbon in the combined state, and that silicon tends in the opposite direction. Professor Howe and Dr. Wüst have endeavoured to arrive at the exact quantitative effect of sulphur and silicon in preventing or facilitating the decomposition of the carbides.

Howe recognised that the data available are insufficient on which to make any final conclusion.

Wüst found, by a series of trials, that in pigs containing 3·15 per cent. carbon and about 1 per cent. silicon, on an average 0·01 per cent. sulphur prevented the separation of 0·02 per cent. graphite, but that with 2 per cent. silicon its effect was much less.

It is the general experience, that the effect of sulphur depends on the proportion, not only of silicon, but of the total carbon and manganese, and of the temperature at which the iron is cast, and the size and temperature of the mould into which the metal is run. Under some critical conditions 0·1 per cent. sulphur may prevent the separation of 3 per cent. graphite.

Howe's discovery—that the tendency of silicon, in increasing the decomposition of the carbides, is rapid at first, especially as the silicon rises from zero to 0·75 per cent., and then slower and slower with each further increase—is very important; so also is the generalisation of Messrs. Charpy and Grenet—that the separation of graphite on annealing iron which is initially white, containing the whole of the carbon in the combined condition, begins at a temperature which is the lower the greater the percentage of the associated silicon, and that the separation of graphite, once begun, continues at even lower temperatures than that at which it started.

The evidence advanced by Phillips, Prost, Campredon, Schulte, and others—that, on dissolving sulphurous irons in hydrochloric acid, all the sulphur is

not given off as H_2S, and that a part either passes off as $S(CH_3)_2$ or remains behind with the solution as some organic product—was tentatively believed as indicative that the sulphur is chemically associated with the carbon and the iron.

Levy,[1] who has done much good work in the endeavour to determine the relations which exist between iron, carbon, and sulphur, in the alloys of these elements, states, as the result of his research, that there is no conclusive evidence of any chemical union.

In his tabulated results showing the amount of sulphur evolved presumably as $S(CH_3)_2$ on dissolving iron, carbon and sulphur alloys, the maximum is 0·06 per cent., but the average is very much less.

Schulte, on the other hand, had found that from 1 per cent. to 12 per cent. of the total sulphur is evolved as an organic sulphur compound; and Bischoff found an even greater quantity.

The results are apparently conflicting, and it is evidently obvious that more research is required in this direction.

It has been shown by Arnold and McWilliam, and confirmed by others, that carbide of iron does not decompose into graphite and iron during the annealing of steel until it segregates into relatively large masses. Taking this as a basis Mr. Levy has advanced an explanatory hypothesis as to how it is that sulphide of iron prevents the decomposition of carbides in white irons. He had found that during the solidification of irons free from silicon and manganese, but rich in sulphur, 'the sulphide separates at a temperature in the neighbourhood of 1130° C., together with, and as a component of, the austenite-cementite eutectic, forming a triple austenite-cementite-sulphide eutectic, the cementite component of which is interstratified with a jointed pearlite (by decomposition of austenite) sulphide one.' He stated that 'The presence of iron sulphide in the eutectic introduces intervening layers, which may partly ball up on annealing, but even then leave sulphide films between the cementite crystals; these act almost as emulsifiers, preventing the coalescence of the cementite portion, which is apparently a necessary preliminary to its decomposition into free carbon and iron. These layers and films are so persistent, even on slow cooling, as to retain their position between the cementite crystals, until the metal has cooled well below the temperature of decomposition, so that an iron which might otherwise become grey is retained, even on very protracted cooling, in the white form, by sulphur as sulphide; 0·25 per cent. sulphur being sufficient for this purpose under the moderately protracted cooling conditions of the research. It is not improbable that the mechanical force exerted by sulphide, on separation and cooling, may also prevent the physical conditions necessary for carbide decomposition, which, as is well known, is accompanied by considerable expansion.'

It is to be noted that Mr. Levy's argument is based on the effect of the sulphide films in the eutectic, preventing the segregation of the cementite into relatively large masses, which, as he expresses it, 'is apparently a necessary preliminary to its decomposition.'

His conclusions were based on the examination of hypo-eutectic alloys containing not more than 2·75 per cent. carbon and free from massive plates of cementite.

Whilst admitting that his conclusions may be correct, as applied to the eutectic, some other explanation would be necessary if decomposition did not occur when a considerable quantity of massive cementite initially were to form in the alloy.

That stable massive cementite can be so obtained in iron sulphide alloys I shall presently show.

If it could be shown that sulphur in some form of combination with the iron and carbon does crystallise with the carbides, and that such mixture or solid solution is stable and not readily decomposed, it would be reasonable to conclude that the sulphur is responsible for the stability.

It has been suggested that silicon in iron decomposes the carbides according to the following chemical reaction: $3Si - {}^2Fe_3C = {}^3Fe_2Si - 2C$. The only objection to this explanation is that the silicon is not free in cast iron, as was proved by Turner, and, moreover, as will be shown presently, it is combined with iron in solid solution before the carbide is decomposed.

[1] *Journal of the Iron and Steel Institute*, No. 2, 1908.

Gontermann[1] found that on adding pure silicon to molten iron, the iron and silicon combined with considerable rise in temperature, and I have noticed the same thing even when adding it to carburised iron.

The same authority, who has made a most careful study of the ternary alloys of the iron-carbon-silicon series, has shown that the eutectic freezing-point rises with the silicon from 1130° when silicon is absent, to about 1150° when it reaches 10 per cent., and to 1175° when it is about 17 per cent., and that the carbon in the eutectic of the alloys containing between 0 per cent. and 10 per cent. silicon, falls as the silicon rises by about 0·3 per cent. for each unit of silicon.

The same author proved that the pearlite reversion-point in these alloys rises with the silicon on an average of about 30° C. for each unit of silicon in the alloys containing between 0° and 6 per cent. silicon. He concluded, but did not actually prove, that in the region of the curve of unvarying equilibrium two cementites crystallise; one a solid solution of the carbide and silicide of iron; and a second, a mixture of this with another ternary iron-silicon-carbon solid solution.

If the composition of the alloy lies between the curve of saturated silico-austenite and the curve of non-varying equilibrium, saturated silico-austenite primarily forms; and following this a secondary crystallisation of a binary eutectic consisting of this saturated austenite and silico-cementite.

In the year 1901 I described certain unique idiomorphic crystals which had been found in the hearth of a disused blast-furnace at Blaina. The crystals were more or less oxidised on their exterior surfaces.

The analysis was as follows :—

	After deducting the Oxygen, &c. Per cent.
Manganese	54·56
Iron	37·71
Carbon	3·91
Silicon	3·82
	100·00

A micro-examination proved the crystals to be quite homogeneous mixtures, or solid solutions. It was difficult to assign to them any definite chemical constitution. They may be considered as silico-carbides of manganese and iron, and, as will be shown presently, bear a close relation to similar crystals which primarily form during the freezing of iron-carbon-silicon alloys.

Having briefly referred to the work of a number of authorities, I now propose to describe my attempts to supplement our knowledge in this direction by a purely micro-chemical research.

In order to understand the remarks which follow, it is necessary briefly to describe the changes which occur when pure iron-iron carbide alloys pass from the liquid to the solid state as are indicated by the researches of Osmond, Roberts-Austen, Stansfield, and of Carpenter and Kneeling

In the iron alloys containing less than the eutectic proportion of 4·3 per cent. carbon, described as hypo-eutectic alloys, austenite octahedral crystallites of the fir-tree type first fall out of solution, and these continue to grow till the liquid is so impoverished of iron and enriched in carbon that when the eutectic proportion of 4·3 per cent. carbon is reached, the liquid solidifies and breaks up into carbide of iron and austenite.

The hypereutectic alloys, containing more than the eutectic proportion of carbon, on cooling, first yield carbide of iron crystals, and these continue to grow till, by removal of the excess carbon, the eutectic proportions of iron and carbon are reached. The eutectic in its turn then freezes.

For the purpose of my research it was necessary to select pig metals, grey and high in silicon and white with high sulphur. These were kindly supplied

[1] *Anorganische Chemie*, Bd. 59, 1908.

by Messrs. Wilson, Pease and Co. and Messrs. Cochrane and Co., Middlesbrough. They were made from Cleveland ironstone and contained :—

—	White	Grey Glazed Iron No. 1	Grey Glazed Iron No. 2
	Per cent.	Per cent.	Per cent.
Combined carbon	2·98	nil	Trace
Graphite	traces	2·65	3·300
Manganese	0·29	0·72	0·676
Silicon	1·89	5·21	4·321
Sulphur	0·27	0·03	0·025
Phosphorus	1·62	1·56	1·660

It may be accepted that the sulphur in the white iron undoubtedly is the cause of the whiteness of the iron, whilst the excessively high silicon and low sulphur are equally responsible for the graphitic condition of the carbon in the grey irons.

The micro-structure of the high silicon metal was characteristic of all phosphoretic, high-silicon, carbon alloys. Curved plates of graphite cut the mass in many directions, whilst the binary eutectic of phosphorus and iron remained in irregular patches, generally midway between the graphite plates. The ground mass occupying the space between the eutectic and graphite plates consisted of silico-ferrite.

The interesting feature about the structure of the white iron is that there was no iron-iron-carbide eutectic. This had been replaced by the ternary eutectic of iron-phosphorus and carbon, which, according to Dr. Wüst, contains about :—

	Per cent.
Iron	91
Phosphorus	7
Carbon	2
	100

There was evidence that the primary crystals of austenite of the octohedral skeleton type had been the first to fall out of solution, that the second crystal to form consisted of short plates of carbide of iron (cementite); whilst the ternary eutectic of phosphorus, carbon, and iron was the last to freeze and occupied spaces between the cementite plates and the primary crystals.

Dr. Carpenter and his assistant, Mr. Edwards, of Victoria University, Manchester, kindly obtained, for the purpose of this address, the cooling curves of these two typical metals. These were as follows :—

Grey Iron.

The long arrest at 1118° indicates a change of state, but is also coincident with important chemical changes. The second long arrest at 945° is due to freezing of the iron phosphorus carbon eutectic. The arrest at 850° indicates the formation of pearlite, and corresponds closely with the arrest in a similar alloy examined by Gontermann. The arrest at 690° is probably due to the formation of pearlite in the eutectic of iron and phosphorus, and is of great interest, for it points to the conclusion that silicon is not a constituent of the austenite of the ternary eutectic.

White Iron.

The micro-structure and analysis help more fully to explain the arrests on cooling this alloy.

The first arrest at 1149° C. is where the primary austenite crystallises with the silicon, as will be shown presently.

The second arrest is where the primary cementite plates freeze.

The third arrest at 945° is the freezing-point of the ternary eutectic, and is identical with that of the corresponding long arrest of the grey iron.

The fourth arrest at 770° is coincident with the formation of pearlite.

Bearing in mind that the manganese in the white iron was insufficient to combine with the whole of the sulphur present to form manganese sulphide, it is

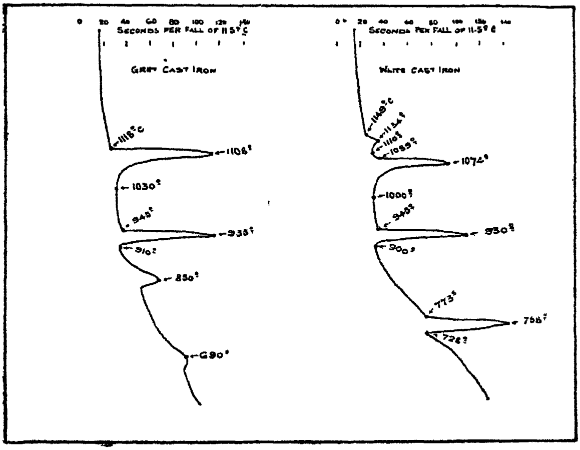


Diagram showing arrest in cooling; grey iron No. 2 on left, white iron on right.

obvious that some other compound or compounds of sulphur existed. The microscope clearly revealed the presence of manganese sulphide and traces of free iron sulphide.

The carbide plates were quite free from striations of sulphide, such as had been noticed by Mr. Levy in the eutectic of high sulphur irons.

But for the sulphur present, the silicon would have been sufficient to effect a decomposition of the carbides, and the metal in absence of the sulphur would have given a grey instead of a white fracture. In view of this conclusion it appeared to be probable that if manganese were to be melted with the metal, it would combine with the sulphur associated with iron, &c., and crystallise as MnS, previous to the solidification of the carbide, or independently, and that the metal would then become grey on cooling.

In order to test this, a portion of the metal was melted in a clay pot with a little pure manganese, free from carbon—sufficient to give one per cent. of manganese, which was more than sufficient to combine with the whole of the sulphur. As soon as the mass was melted it was at once poured into a sand mould and allowed to set. When cold, it broke with a grey fracture corresponding to what is known as hard forge, and the combined carbon instead of being about three per cent. was reduced to 0·6 per cent., a result proving the correctness of the hypothesis.

It is well known that when manganese or chromium and some other metals are present in large quantities in pig irons, these metals, as carbides, crystallise with the carbide of iron forming double carbides, and these are much more stable than the massive pure iron carbide. It appeared reasonable to believe that if sulphide of iron, or some iron-sulpho-carbon compound, were to crystallise with the carbides it would have a similar effect.

Remembering that the conclusions on this question, as to whether sulphur does or does not crystallise with the carbides, are conflicting, it is evident that the only possible way to find out whether sulphur does so crystallise is to separate the carbide from the iron and test it for sulphur. With this object, a considerable quantity of the original Cleveland white metal was crushed to the very finest powder. It was then treated with a 10 per cent. solution of hydrochloric acid in water in large excess, and the action of the acid was allowed to continue until

evolution of gas ceased. The insoluble matters, consisting mainly of carbides and phosphides, were filtered off, washed and dried, and were ground down in an agate mortar to a still finer powder, so as to liberate any mechanically entangled sulphides. The powder so dealt with was again treated with acid as before, after which the residue was filtered off, thoroughly washed with water, was transferred to a separate vessel, and was boiled with strong caustic-potash to dissolve any decomposition products.

The residue was again filtered off, was washed and dried, and submitted to analysis. The residue when dried weighed about 45 per cent. of the original metal, and contained as follows :—

	Per cent.	
Iron	92·43	
Carbon	6·06	
Silicon	0·12	
Sulphur	0·12	
Phosphorus	0·97	(6·2 per cent. phosphide of iron)
Water, &c.	0·30	
	100·00	

A second trial was made with the same metal; but, in this case, repounding and acid treatment were repeated three times, so as to eliminate the possibility of mechanical inclusion of sulphide or iron. The sulphur found in the remaining carbides was 0·1 per cent.

As the manganese in this metal was not sufficient to form manganese sulphide with the sulphur, it seemed desirable to determine whether or not when the manganese is in sufficient quantity sulphur would crystallise with the carbide. For this purpose the white chilled part of a crushing roll was experimented upon. The centre part was open grey iron, and contained 3·1 per cent. of the carbon as graphite.

The white chilled portion contained :—

	Per cent.
Combined carbon	3·75
Graphitic carbon	Trace
Manganese	0·65
Silicon	0·70
Sulphur	0·10
Phosphorus	0·23

It was crushed to powder and treated exactly in the same way as previously described for the separation of carbide. The residue contained by analysis :—

	Per cent.
Silicon	0·028
Sulphur	0·016

a result showing that only a minute quantity of sulphur was crystallised with the carbide. Whether a different result would follow if both sulphur and manganese were greatly increased has yet to be determined.

Having proved that sulphur in some undetermined state of chemical combination does crystallise with carbide of iron, an attempt was made to determine the maximum amount of that element the carbide will retain under the most favourable conditions. With this object in view a considerable quantity of very pure white iron, containing only traces of silicon, sulphur, and phosphorus, and 3·5 per cent. of carbon, was melted in a plumbago crucible; and when in a molten condition sticks of roll sulphur were forced under the surface of the metal, and afterwards the mixture was briskly shaken up with the sulphur which had liquefied on the surface.

Precisely the same result was obtained as described by Karsten, who had made a similar experiment. A metal was produced having a white fracture and large cleavage faces. The micro-structure was similar to that of hypereutectic iron carbon alloys. Large plates of carbide cut the metal in many directions, whilst between the carbide plates was located the triple carbide-sulphide-pearlite eutectic, so accurately described by Mr. Donald Levy.

The carbide plates themselves were peculiar in having circular prismatic in-

clusions of sulphide of iron symmetrically arranged at right angles to the sides of the plates. In horizontal sections of these plates they appeared as circular dots, sometimes arranged in continuous lines, suggesting that the sulphide had been actually in solution with the carbide when the metal was liquid, that they fell out of solution together, the sulphide separating and segregating along the cleavages of the carbide.

A portion of this sulphurous material was remelted and treated with a second quantity of sulphur. This time in addition to sulphide of iron a considerable quantity of the soot-like substance described by Karsten floated to the surface, and free graphite separated and stuck to the sides of the crucible.

The analyses of these metals are as follows :—

	After the first addition of Sulphur. Per cent.	After the second treatment with Sulphur. Per cent.
Carbon	4·37	4·39
Sulphur . . . about	1·00	1·00
Silicon	0·03	0·05

From which we may conclude that the maximum degree to which the carbon can be concentrated by this method is about 4·4 per cent. In these trials the carbide certainly had sufficient opportunity to become saturated with sulphur in each case. Both of the metals were crushed to exceedingly fine powder, and were treated with acid to decompose the free sulphides. The residues were repounded and treated with acid a second time, and afterwards with strong potash solution. After this treatment, analyses of the insoluble residues indicated, in one case 0·09 per cent. sulphur, and in the other 0·08 per cent. *From this it would appear that carbides will not crystallise with more than about* 0·1 *per cent. of sulphur.*

The metal containing 4·37 per cent. carbon and 1 per cent. sulphur, even on prolonged annealing, did not become graphite, a proof that the massive carbides present were quite stable.

The microscope reveals the fact that in almost all commercial white irons containing much sulphur the greater part of the sulphur is combined with either manganese or iron, and that the sulphides mainly exist as independent inclusions. It appears reasonable to assume that the manganese sulphide is without influence on the carbon condition, and that, although iron sulphide may have some influence, in the way suggested by Mr. Levy on the eutectic, *it is the sulphur that crystallises with the carbide which is mainly responsible in preventing the separation of graphite by making the carbide more stable.*

If it is assumed that the stability of the carbide depends on the quantity of sulphur which crystallises with it, and not on the total amount present in the metal carrying the carbides, it is clear that a great field of research is now open, the borders of which I have barely touched to co-relate their stability and sulphur contents.

The microscope does not show in what constituent the silicon crystallises. It is known that in grey irons it is associated with the ferrite and pearlite, but grey iron is the final result of the decomposition of carbide of iron and possibly silico-carbides, which primarily form during solidification, and although the silicon in the decomposed product may be entirely associated with the iron it is no proof that initially some of it may not have crystallised with the carbides.

In the white Cleveland iron, previously referred to, it is probable that the several constituents are present in the following proportions :—

	Per cent.
Silico-pearlite, the residue of the original austenite octahedral crystallites	42·50
Iron carbide in plates	33·66
Iron, phospho-carbide eutectic	23·10
Manganese sulphide	0·38
Iron sulphide	0·36
	100·00

When fractionally dissolving the powdered metal in acid, it was the iron and associated silicon of the pearlite which passed into solution, and the carbide and phosphide which remained insoluble, and as these contained only 0·12 per cent. silicon, or about 0·06 per cent. on 100 parts of the original metal, it is evident that the pearlite must have contained $1{\cdot}89-0{\cdot}06=1{\cdot}83$ per cent. of the silicon, or on 100 parts of it $\frac{100\times 1{\cdot}83}{42{\cdot}5}=4{\cdot}3$ per cent., and that about 97 per cent. of the total silicon had crystallised with the austenite.

A little reflection will lead to the conclusion that if the carbon in the Cleveland white iron were to be gradually increased, the proportion of primary austenite crystallites would decrease, there would be less and less of them to carry the silicon, and this element would be concentrated in the diminishing solid austenite. It also follows that if the carbon were to be so increased that no primary austenite would form, the silicon would have to crystallise in some other constituent.

In the example, referred to above, of the chilled casting, the carbides contained only 0·028 per cent. silicon, or 0·016 per cent. on the original metal. In this case, therefore, about 98 per cent. had crystallised with the primary austenite.

The question as to what amount of silicon will crystallise with the austenite so as to saturate it is probably variable with other variables. To determine this by chemical analysis would involve an exceedingly tedious research.

It is probable that as it increases, and as the austenite approaches more and more nearly to the saturation point, a gradually increasing proportion of the silicon will crystallise with the carbides.

It is well known that molten low silicon grey irons, in the absence of any appreciable quantity of sulphur, gives a white fracture when slightly chilled. Irons with above five per cent. silicon, when similarly treated, are supposed not to behave in the same manner; and this is quite true when any ordinary method of chilling is adopted. For instance, when the liquid silicious glazed metal No. 1 was run into water, the chilled iron contained graphite; but when a large drop was suddenly pressed into a sheet as thin as paper between cold plates of iron, the chilled metal was quite white and no graphite could be detected on dissolving it in nitric acid. The metal so chilled was difficult to dissolve in acid, and the silica produced, instead of forming a gelatinous bulky residue, remained in a close dense condition—indeed the thin chilled sheet, after all soluble matter had been removed, remained a rigid sheet of dense coherent silica, whereas the same metal allowed to cool slowly from the liquid state in a sand mould yielded to acid gelatinous silica.

The different behaviour to acid treatment of the chilled as contrasted with that of the slowly-cooled metal indicates that the condition of the silicon in rapidly chilled metal is different from its condition in the same metal slowly-cooled.

In 1895 Mr. T. W. Hogg, of Newburn Steel Works, published an account of a very interesting observation, in which he showed the difference in the silicon solubility in different parts of the same pig iron—a portion of which was white and a portion grey. The iron referred to contained:—

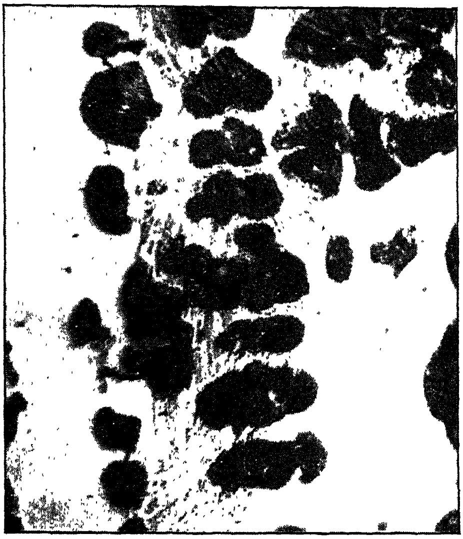
	White part. Per cent.		Grey part. Per cent.	
Combined carbon	3·88	4·33	0·98	4·66
Graphitic carbon	0·45		3·68	
Silicon	0·65		0·85	
Manganese	1·63		1·60	

He determined the solubility in dilute acid of the silicon in each portion, and found that the silicon soluble in hydrochloric acid was, in the grey part=about 81 per cent. and in the white part=about 48 per cent.

He found also that the silica left on treating the two varieties of metal in acid differed in character—that from the white portion was dense, whilst that from the grey metal was much more voluminous. The white metal contained the eutectic proportion of carbon, and therefore it could not contain any austenite crystallites; indeed with the silicon 0·60 per cent. also present it must be regarded as a hypereutectic alloy, and on that account we are forced to conclude that the silicon must have crystallised with the carbide.

No. 1.

Cleveland White Iron.



White=massive plates of Fe_3C.
Dark=pearlite, the decomposed austenite.
White and half-tone=ternary Fe—C—P eutectic.

No. 2.

Cleveland Glazed Iron.

Ground mass=silico-ferrite.
White complex=iron—iron phosphide eutectic.
Straight dark lines=graphite.

Illustrating the Presidential Address to Section B.

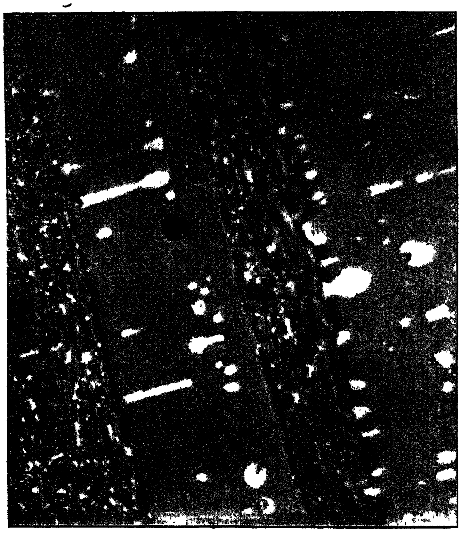
No. 3.

Iron-Carbon-Sulphur Alloy (4·37 per cent. Carbon).

White thick bands=massive carbide of iron.
Complex structure=iron—iron-carbide-sulphide-pearlite eutectic.

No. 4.

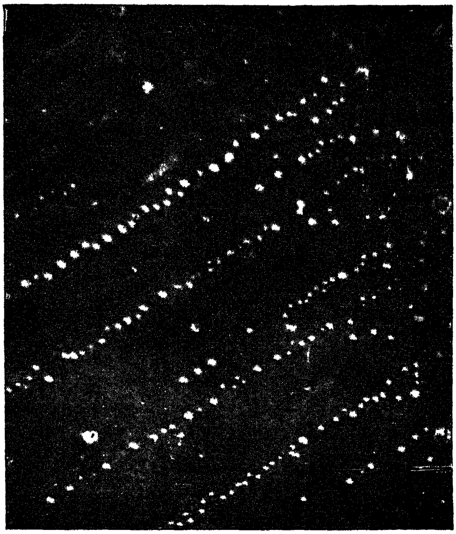
Same as No. 2, heat-tinted and more highly magnified.



Broad bands=massive carbide of iron with inclusion of sulphide of iron.
Complex structure=jointed eutectic of Fe—Fe_3C—FeS.
The white specks are all FeS.

No. 5.

Same as No. 4. Section cut parallel to the surface of a massive carbide plate.



The ground mass is carbide of iron.
The white dots are sulphide of iron.

No. 6.

Glazed Cleveland Iron after melting with a little Sulphide of Iron.

White crystals = primary carbo-silicide of iron.
Dark = the second cementite.
Complex structure = iron-carbon-phosphorus eutectic.

No. 7.

An Iron-Carbon-Silicon Alloy, free from Phosphorus, made more stable by Sulphur.

Broken up structure in the centre = the eutectic of two cementites, silico-carbide and carbide.
Half-tone = the carbide cementite.
Dark area = decomposed eutectic.
Light portion at right lower corner = crystallite of silico-pearlite.

No. 8.

Pure Iron-Iron Carbide Eutectic, the cooling of which was arrested before the complete decomposition of the Carbides into Austenite and Graphite.

White = carbide of iron. Black lines = graphite. Half-tone = pearlite.

It has long been known that on dissolving grey ferro-silicon containing even six per cent. silicon the silica gelatinises, whereas when the silicon approaches 10 per cent. much of the silica remains in a dense form. It is almost certain that during the solidification of the grey part of Mr. Hogg's pig iron a rich silicon cementite must have primarily formed, for the high carbon would not allow the formation of any primary silico-austenite; when this cementite decomposed the silicide part of it would become diluted with the iron of the decomposed carbide. It was, no doubt, this diluted solid solution in the cold grey metal which yielded the gelatinous silica.

That silicon does diffuse into iron, even at relatively low temperature, was proved by Lebeau. He found that free silicon and iron, when heated together *in vacuo* at 960° C., chemically combine, a fact I have fully confirmed, although it is impossible to get silicon to combine with iron on heating them together in a cementation furnace where oxidising gases have access to the silicon.

To determine whether silicide of iron would diffuse into and precipitate the graphite in white iron, a sample of crushed white iron free from impurities, containing 3·5 per cent. of carbon, was mixed with 10 per cent. by weight of a silicon alloy containing 20 per cent. of silicon ($=Fe_2Si$) also in powder. The mixture after compression in a short piece of iron tube was heated for two hours at 1000° C., in an atmosphere of hydrogen gas, and was then removed and cooled in air.

For comparison a portion of the crushed white iron was treated in the same way.

The combined carbon in the metals before and after heating were as follows :—

	Before. Per cent.	After. Per cent.
In white metal alone	3·5	3·44
„ „ and silicide	3·20	0·60

Not only does this trial prove that silicide does diffuse into carbide of iron and precipitate graphite, it has also an important bearing on the question as to why silicon in pig-iron, even in small quantities, causes the carbide to be decomposed. In the experiments with the chilled part of a casting containing only 0·7 per cent. silicon and 3·75 per cent. carbon it was shown that the carbide contained only 0·028 per cent. silicon, and that 98 per cent. of the total silicon was concentrated in the pearlite; yet this white iron on heating to 1000° C. became quite grey. *Are we not justified in concluding that it was the diffusion of silicide of iron from the silico-austenite into the carbides which caused the separation of graphite?*

As I had proved, first that sulphur crystallises with and makes the carbide of iron more stable, and second that in the presence of a fusible mother liquor rich in phosphorus, after the austenite crystallisation is complete, the carbide crystallises out in plates and not as iron carbide eutectic, it appeared probable that if, as Gontermann premised, two kinds of cementite actually form during the solidification of iron-carbide-silicon alloys, it might be possible to obtain them in a separate state by melting the rich silicon alloys with a little sulphur.

In order to test this a portion of the No. 1 grey glazed metal was melted, and when fluid a little sulphide of iron was mixed with it. The mixture was then cast in sand. Owing to the rapidity of the melting some of the graphite escaped and floated on the surface of the metal.

When cold it was found that the lower part of the small casting gave a white fractured surface, whilst the upper part was close grey.

The analyses were as follows :—

	White part. Per cent.	Grey part. Per cent.
Combined carbon	2·06	0·60
Graphite	Trace	1·46
Manganese	0·03	0·03
Silicon	5·41	5·40
Sulphur	0·88	0·91
Phosphorus	1·50	1·50

The grey part, although slowly attacked by cold acid, did dissolve, yielding much voluminous silica. The white part was almost inert and only dissolved in strong hydrochloric acid with difficulty, and when the iron was dissolved out the remaining silica was of the dense variety, from which it would appear that the effect of the sulphide is akin to that of sudden quenching.

It was the micro-structure of the white portion, however, which was of unique interest. On 'heat-tinting' two kinds of hard crystals appeared, one more readily coloured by heating than the other. The more resistant crystals were idiomorphic, and were furnished with their terminal angles, but as they were embedded in the surrounding metal it was impossible to form any exact idea of the crystalline system to which they belong.

The second order of crystals had evidently solidified at a later period, as their forms were interfered with by those of the idiomorphic type; they were much like ordinary plates of carbide of iron. The ground mass contained indications of octahedral on fir-tree crystallites and a well-developed phosphorus iron eutectic of the honeycomb type. This eutectic was the last to freeze, as it filled the spaces between the plates of the hard crystals. There was no pearlite excepting in the eutectic of phosphorus and iron. We can only tentatively conclude that of the two cementites the idiomorphic crystals contained the greater part of the silicon because of their greater resistance to oxidation and probably consisted of carbo-silicide of iron, with sufficient sulphur in them to make them stable; also that the second crystals were carbide of iron, possibly containing a lesser quantity or no silicide in solid solution.

A further series of experiments was made on a portion of the same metal. In this case the molten iron was mixed and agitated with free sulphur instead of sulphide of iron, and the metal was at once poured into a sand mould in a thin layer. When cold it was quite white in fracture and had large brilliant cleavage faces.

It had the following composition:—

	Per cent.
Combined carbon	2·60
Manganese	Trace
Silicon	6·65
Sulphur	0·93
Phosphorus	2·08

The sulphur had evidently effected concentration of the silicon phosphorus and carbon by removing some of the iron, as sulphide of iron was actually formed and floated on the surface of the iron. It was fractionally dissolved as described in previous cases, and the residue (72 per cent. of the weight of the original metal) was tested and found to contain:—

	Per cent.
Carbon	2·92
Manganese	Trace
Silicon	6·70
Sulphur	0·062
Phosphorus	1·410

This insoluble fraction evidently consisted of both classes of crystals, together with some phosphide of iron. Efforts were made to separate the crystals by chemical means, but without success.

On the long and continued action of strong hydrochloric acid a residue was obtained containing a little less carbon and more silicon than were present in the mixture, an indication that the less soluble portion is different from that more soluble.

The micro-structure was similar to that of the metals of the previous trial, but as the carbon and silicon were higher the carbo-silicide was in greater quantity. It crystallised in long flat plates and not in relatively short idiomorphic crystals.

It is probable exception may be taken, with some justification, that the sulphur does not simply arrest the decomposition of the cementites, which I have premised primarily form, but may act in some other unknown way. An attempt was therefore made to find out whether they could be obtained by some other method without the aid of sulphur. As it is known that the ternary eutectic

of iron, phosphorus, and carbon melts at about 945° C., it appeared probable that if silicon in small quantity were to be melted with an iron-carbon-phosphorus alloy very rich in phosphorus the two kinds of cementites would fall out of solution at a lower temperature, and would probably not decompose into graphite and silico-austenite in cooling down after their formation. To ascertain whether or not this would be the case, a fusible iron-phosphorus-carbon alloy containing more than the eutectic proportion of carbon was made. It had the following composition :—

	Per cent.
Iron	91·89
Phosphorus	5·37
Carbon	2·62
Silicon, &c.	0·10
Sulphur	0·02
	100·00

Four hundred grams were melted with sufficient silicon alloy to yield in the mixture :—

	Per cent.
Carbon	2·4
Phosphorus	5·0
Silicon	2·90
Sulphur	0·02

When melted a portion of it was cast in a sand mould, the remainder was allowed to cool in the crucible.

When cold, that cooled in the crucible was quite grey, whilst the portion cooled in sand was white at the lower part and grey on the top part of the casting, results which proved that the alloy was very unstable and that decomposition of the lower part of the casting was arrested by the slight chilling effect of the cold sand.

On microscopic examination of the white portion the ground mass was found to consist of the binary phosphorus iron eutectic, whilst two different cementites were embedded in it, one much more rapidly coloured on 'heat-tinting' than the other. The colours of the constituents of the properly heated and polished metal were as follows :—

Cementite (*a*)	White
„ (*b*)	Red
Phosphide of iron	Purple
Iron pearlite crystallites	Grey

The part which broke with a grey fracture consisted of octahedral crystallites of silico-pearlite, the binary phosphorus iron eutectic, and undecomposed (red) cementite crystals, but there was a complete absence of the (white) cementite crystals. Graphite was also present in exceedingly fine plates, resembling what is known as temper graphite.

The evidence here is conclusive that even in the absence of sulphur :—

(1) Two cementites had formed.

(2) That one cementite is much more unstable than the other variety, and decomposes in advance into silico-austenite and graphite.

Having proved that two different kinds of cementite do actually form and crystallise in the phosphorus eutectic it remained to ascertain in what way these crystallise in the absence of the phosphorus eutectic.

For this purpose two hypo-eutectic alloys were prepared without any phosphorus, but with sufficient sulphide of iron to check the decomposition of the carbides.

They contained :—

	(1) Per cent.	(2) Per cent.
Carbon	2·40	2·10
Silicon	3·17	7·10
Sulphur	1·21	0·82
Phosphorus	0·02	0·02

These when cold after casting in sand broke with white fractures.

The carbides separated in the manner previously described contained :—

	(1) Per cent.	(2) Per cent.
Carbon	6·16	3·00
Sulphur	0·09	0·08
Silicon	0·97	7·93
Percentage of carbides insoluble in acid	27·5	50·00

The repeated acid treatment in this, as in all previous cases, no doubt dissolved a portion of the carbides, and what was actually weighed represented only a part of those actually present in the alloys.

In No. 2 alloy, after polishing and 'heat-tinting,' the microscope proved the presence of a few fir-tree crystallites embedded in a ground mass of cementite and a eutectic containing the two kinds of cementite, the No. 1 specimen containing a much smaller proportion of the cementite rich in silicon than No. 2.

As the metals had been somewhat rapidly cooled the alloy No. 2 was remelted, and was then allowed to cool in the crucible, so as to obtain a more coarsely crystallised eutectic. When cold, on polishing and 'heat-tinting,' the eutectic was clearly seen. There were the remains of large primary silico-austenite crystallites, plates of the red-coloured cementite, and a well-developed eutectic consisting of the (red) coloured and (white) cementites.

The cooling having been slow, this compound constituent had suffered partial decomposition in isolated patches into graphite and silico-ferrite, whilst the cementite coloured red remained intact.

There can be little doubt that the residue left insoluble in acid consisted of the two cementites, but in what proportion it is impossible to tell, as a method for isolating them has yet to be found.

Had the alloy contained a greater proportion of carbon the amount of cementite rich in silicon would have been in much greater proportion.

The trials, incomplete and necessarily imperfect as they are, go far to prove, just as Gontermann premised, that during the solidification of high silicon pig-irons two cementites fall out of solution together as a eutectic mixture.

They also have proved that the carbo-silicides are exceedingly unstable, breaking up into silico-austenite almost as soon as formed. *It is the instability of these silico-carbides which is mainly responsible for the graphitic character of grey irons rich in silicon and low in sulphur.*

Summary and Conclusions.

1. The experimental results advanced show proof that carbide of iron in presence of iron sulphide crystallises with a minute quantity of sulphur not exceeding about one-thousandth part of the weight of the carbide, but the nature of the iron-carbon-sulphur compound has not yet been determined.

2. It seems almost, if not absolutely, certain that it is the sulphur crystallised with the carbide which makes the latter stable.

3. The evidence appears to support the view, long held by some and more recently accepted by others, that during the freezing of iron-carbon-hypo-eutectic alloys after the crystallisation of the primary austenite, and in the eutectic and hypereutectic alloys, it is the carbide and not graphite which primarily forms and that the carbide afterwards decomposes into graphite and austenite.

4. It has been proved by chemical methods that when the hypo-eutectic alloys, low in silicon, freeze, nearly all the silicon crystallises out with the primary austenite; and it follows that on gradually increasing the carbon so as to reduce the quantity of primary austenite, the silicon remaining constant, the austenite which does form must be as gradually enriched in silicon up to saturation-point; and, when that point is reached, the excess silicon crystallises out with a portion of the carbide of iron to form carbo-silicide of iron. Other elements remaining constant, the same result must follow on gradually increasing the silicon.

5. In the alloys of eutectic proportion and in the hypereutectic alloys, as no primary austenite can form, the silicon crystallises primarily with the carbide.

6. In Cleveland pig-iron containing about 1·5 per cent. phosphorus, a ternary eutectic of iron-carbon-phosphorus takes the place of the iron-iron-carbide eutectic.

In white irons containing 3 per cent. carbon and under 2 per cent. silicon, after the primary austenite has fallen out of solution carrying practically all the silicon, it is not iron-iron-carbide entectic which forms, but independent plates of cementite, or carbide of iron, and after these have crystallised and the residual mother liquor has arrived at the composition of the ternary iron-carbon-phosphorus eutectic, the latter solidifies at 945° C.

7. In Cleveland irons which become grey on cooling, and in which there is no primary austenite, the same iron-carbon-phosphorus eutectic is the only eutectic to form during cooling, and, instead of a ternary iron-carbon-silicon eutectic, two independent cementites crystallise—one a silico-carbide, and the other carbide of iron possibly containing a little silicide in solid solution. The micro-examination of the cold alloys, to which a little sulphur had previously been added when the metals were melted, led to the conclusion that it is the carbo-silico-cementite which primarily crystallises.

8. There is evidence that the primary carbo-silicides are exceedingly unstable and are the first to decompose into graphite and silico-austenite.

9. In the absence of any sensible quantity of phosphorus, two cementites form —one the silico-carbide cementite, the other the carbide cementite—and these crystallise together as a eutectic mixture.

10. The exact composition of the two cementites has not yet been determined, as no chemical method has been found for their isolation.

11. It is evident that it is the exceedingly unstable character of the silico-carbides which is responsible for the greyness of commercial metals rich in silicon and low in sulphur.

12. Silicide of iron when heated at 1000° C. with pure white iron free from silicon effects the decomposition of the carbide of the white iron. Based on this observation the hypothesis seems justifiable, in cases where all the silicon present in hypo-eutectic alloys crystallises out with the primary austenite, that after the carbide has solidified, diffusion of the silicide follows, and this leads to the decomposition of the carbide of iron into graphite and iron.

13. Many of the results arrived at by chemical analysis support the hypothetical conclusions of Gontermann, who depended mainly on data obtained by thermal methods of treatment.

In conclusion, it will be clear from what I have stated that there are many gaps yet to be filled. I hope that the knowledge of this fact will lead others to follow up the research, which, in its present stage, is far from complete.

NOTE.—The terms carbide cementite and silico cementite are used tentatively. Strictly, there is only one cementite and that is F_3C.

FRIDAY, SEPTEMBER 2.

Joint Meeting with Section A.

Discussion on Combustion.—See Reports, p. 501.

MONDAY, SEPTEMBER 5.

Joint Discussion with Sections I and K on the Biochemistry of Respiration.—See p. 762.

The following Paper was then read :—

On the Influence of the Pressure, Humidity, and Temperature of the Atmosphere on the rate of Metabolism in Animals. By WM. THOMSON.

Briefly stated, a rise in the barometric pressure or a rise in the humidity of the atmosphere produces a lowering in the percentage of CO_2 in the exhaled air,

whilst a fall in the pressure or a fall in the degree of humidity produces an increase in the percentage of the CO_2 in the exhaled air.

Different individuals exhale air having different ranges as regards the percentage of CO_2. Thus one man, W. W. (38), breathing Manchester air under normal conditions gave between 3·7 and 4·3 per cent. CO_2; N. T. F. (21) from 3·6 to 4·3; I. W. (22) 5·4 to 6·2; and B. S. (a boy of 14), from 4·2 to 5·3.

Experiments were also made with guinea pigs and with mice. These were put under a bell-jar, fresh air being led in at the top and withdrawn from the bottom, the air being passed finally through a delicate gas-meter by means of a water vacuum pump. The air passed through a litre bottle before and after leaving the bell-jar. The CO_2 were determined in each by baryta water (standard solution). Generally speaking the same rises and falls in the grammes of CO_2 per kilo. weight of animal were obtained from them as from ourselves when they were under similar atmospheric conditions. The higher the temperature of the air the lower the percentage of CO_2 in the exhaled air, and *vice versâ*.

Joint Discussion with Section L on the Neglect of Science by Industry and Commerce.[1]—*Opened by* R. BLAIR.

TUESDAY, SEPTEMBER 6.

FIRST DIVISION.

The following Papers and Report were read :—

1. *On a Fourth Recalescence in Steel. By* Professor J. O. ARNOLD.

2. *Allotropy or Transmutation? By* Professor HENRY M. HOWE, *LL.D.*

If after defining 'elements' as substances hitherto indivisible, and different elements as those which differ in any one property, and after asserting that the elements cannot be transmuted into each other, we are confronted with the change from diamond into lampblack, and with the facts, first, that each is clearly indivisible hitherto and hence an element, and, second, that they differ in every property, we try to escape in a circle by saying that they are not different elements because they do change into each other. In short, we limit the name 'element' to indivisible substances which cannot be transmuted into each other, and we define those which do transmute as *ipso facto* one element, and then we say that the elements cannot be transmuted. Is not this very like saying that, if you call a calf's tail a leg, then a calf has five legs? And if it is just to reply that calling a tail a leg does not make it a leg, is it not equally just to reply that calling two transmutable elements one element does not make them so?

Is the fact that two such transmutable elements yield but a single line of derivatives really proof that they are one element? Is not this rather proof of the readiness, indeed irresistibleness, of their transmutation? Does not this simply mean that the derivativeless element, whenever it enters into combination, solution, or the gaseous state, inevitably transmutes into the one which has derivatives? Does not the theory that a given change is allotropy rather than transmutation need further and more conclusive evidence before it can be taken as proved?

We have become so accustomed to the present point of view that it seems to us second nature; but, if we look frankly at it, is it a tenable or philosophical point of view?

This question is not without a practical application. If, instead of saying 'The elements cannot be transmuted into each other,' we were to say 'Hitherto no elements have been transmuted into each other except those which transmute so readily that the derivatives of only one of them have been recognised,' we should take a point of view from which the transmutation of, say, copper into lithium ceases to be so improbable antecedently as to call for extraordinarily conclusive evidence.

[1] See *The School World*, October 1910.

3. *The Closing and Welding of Blowholes in Steel Ingots.* By Professor Henry M. Howe, *LL.D.*

In the solidification of molten or liquid substances, especially those of high melting-point, two classes of cavities are likely to form: gas bubbles called 'blowholes,' and a central contraction cavity called a 'pipe.'

The blowholes represent (*a*) the progressive concentration in the molten or liquid mother mass of the gases initially present, a concentration carried on to supersaturation, and to the liberation of part of this gas from the supersaturated layers; and perhaps (*b*) in some cases, such as that of the solidification of steel ingots, the formation of a gas from chemical reaction brought about by fall of temperature or by passage from the liquid to the solid state. In the case of steel ingots there are indications that carbonic oxide is thus formed during solidification by the union of carbon and oxygen present side by side in the molten metal.

The formation of the central 'pipe' is due to the cooling, and hence contraction of the different layers of the mass æoliotachically, *i.e.*, at different rates *inter se*. In the first stages of solidification the very outside of the mass, especially if it is cast in a cold iron mould, cools much faster than the still deeper seated layers. The early excess of contraction of the skin, caused by this excess of cooling, is resisted by the lagging interior, with the result that the skin is virtually stretched beyond its normal dimensions, so that when solidification is complete the interior, which in the latter part of the cooling has to cool through a greater range of temperature and hence has to contract more than the skin, no longer suffices to fill that skin completely, and this deficit of volume of the interior is represented by a central cavity overlying the region in which the last of the solidification occurs. This same excess of contraction of the earth's crust in its early stages should later throw that crust into great compression, which may be an important element in volcanic and earthquake phenomena.

Blowholes themselves tend in effect to expand the volume of the interior as a whole without changing the volume enclosed by the skin—*i.e.*, the outer dimensions and thus to lessen the deficit or pipe.

In case of steel ingots this pipe may reach very deep into the axis, and, because it is hard to work up, may compel us to disregard as much as one-third of the ingot in order to get sound unpiped metal. To avoid this some makers of steel of a composition favourable to welding have purposely allowed blowholes to form rather abundantly, so as to prevent the formation of a pipe, and, relying on the ease with which such steel welds, have tried to get flawless metal by welding these blowholes up in the process of rolling the ingot out into its final form, such as that of a boiler plate.

This procedure is of great economic importance, in that it enables the steel-maker to avoid the serious discarding which would be necessary in case his ingots were free from blowholes and hence deeply piped. But many intelligent metallurgists have condemned this practice on the ground that the closing of blowholes is impossible, because the gas which they contain must remain ever present during the rolling, though of course somewhat compressed.

In some late investigations I have carried out two lines of inquiry as to whether the gas of the blowholes is qualitatively absorbable and whether the sides of the blowholes themselves are qualitatively weldable under the conditions of actual manufacture. Both lines proceed by comparing the metal in slabs cut from the original ingot without rolling, with metal cut from a boiler plate into which that same ingot was rolled, and cut in such a way as to separate and distinguish those parts of the metal in the plate which had originally been porous when in the ingot from those which had originally been compact.

The first line showed that the enormous differences in density which existed between the porous and the compact parts of the ingot were practically completely obliterated in rolling the metal down into a boiler plate. In one case the initial difference of 16 per cent. in density was completely removed; in the other the initial difference of 10 per cent. in density was reduced to one-fiftieth its original quantity.

This tended strongly to confirm the strong antecedent probability that the blowhole gases could be reabsorbed during the rolling process, thanks to its high temperature and pressure.

The second line of inquiry disclosed what traces of blowholes remained in the boiler plate by cutting very thin slices lengthwise and crosswise from that plate, mirror-polishing them, and then bending them double in such a way that any blowhole traces present ought to gape open like the cards of a bent pack. Had there been no welding of blowholes this bending should have disclosed unwelded seams about 3.5 inches long and 1.3 inch wide. In point of fact the traces detected were so short as to indicate strongly that a very great degree of welding had occurred. It had seemed to me extremely probable, antecedently, that such welding ought to occur; but here some very competent writers had differed from me. The longest single trace was 0·7 inch long. Only one important 'string' of such traces was found and this was only 0·3 inch long. Further the scantiness of these relics of blowholes tends to show that the blowhole gases have been reabsorbed by the metal to a very great degree. I suggest that such relics of blowholes as have persisted represent in most cases spots where the reabsorption of the gas has become complete after the temperature has fallen too low to permit welding. I therefore suggest prolonging the exposure to a temperature above the welding-point, so as to complete the reabsorption of gas while the metal is still weldable.

The reabsorption of the blowhole gases and the welding of the blowholes ought to be promoted rather by the practice of 'reheating' than by that of 'direct rolling.' In the former the ingot is rolled part way towards its final shape, and the resultant 'bloom' is then reheated before further rolling; in the latter the ingot is rolled to its final shape, such as a rail or a boiler plate, at a single heat. During the early part of the rolling the metal surrounding each blowhole should become strongly charged with gas reabsorbed from that blowhole because of the enormous pressure caused by rolling. To reheat the bloom exposes it for a long time to a high temperature in the heating furnace, during which time the gas dissolved in the metal immediately around the blowhole has an opportunity to diffuse away, leaving that metal free to absorb a new lot of gas from the blowhole. And further, the high temperature of the rolling immediately after this reheating facilitates both the further absorption and outward diffusion of whatever gas remains in the blowholes and the welding up of their sides.

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4. *The Provident Use of Coal.* By Professor H. E. ARMSTRONG, *F.R.S.*

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5. *The Influence of Chemical Composition and Thermal Treatment on Properties of Steel. By* Professor A. McWILLIAM, *A.R.S.M., M.Met.*

Sheffield is pre-eminently the home of the manufacture of special steels, and she attains her ends by strict attention to ultimate chemical composition, by insuring the presence of the most desirable amounts of beneficial substances, and the practicable minimum of deleterious contents, be they the well-understood, such as sulphur and phosphorus, or the more or less mysterious, such as oxygen; and also to those thermal changes called heat treatment, that are produced, sometimes slowly, as in annealing, sometimes suddenly, as in quenching, and that vary the chemical composition or the physical nature of the several constituents, and the mechanical and other properties of their aggregate, the finished steel. Carbon is the chief of the elements that are varied to obtain the different properties required in steels, and typical examples were given of the change in properties produced by the gradual increase in the content of carbon, which, at least in normal steels, is present as carbide of iron (Fe_3C). Other elements are added to vary the properties of the steel, probably mainly by their influence on the nature, the composition, or the distribution of the carbide in the steel. The properties of a series of steels with varying carbon contents, but containing in addition about one per cent. manganese, were shown, and a similar series containing two per cent. chromium, all from results quite recently obtained by the author and Mr. E. J. Barnes. Examples of steels of similar carbon contents containing (1) no special element, (2) one per cent. manganese, (3) two per cent. chromium, (4) vanadium and chromium, (5) nickel and chromium, were tabulated to show the comparative influence of these various additions.

The effects of such heat treatments as long annealing and quenching, followed

by tempering at different temperatures, on selected examples of the above special steels were explained, and finally comparative tables with carbon contents and heat treatments as nearly alike as could be selected, and varying only in the special element added, to show the very considerable and abiding influence of the fundamental chemical composition. Photo-micrographs of the more interesting types were also exhibited and described.

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6. *Ferro-Silicon; with special reference to Possible Danger arising from its Transport and Storage.* *By* Dr. S. M. Copeman, *F.R.S.*

The possibility of danger to life from the transport of ferro-silicon (an alloy or eutectic mixture of iron and silicon employed in the manufacture of steel) had already received official attention in this country through a 'Notice to Shipowners, Shipmasters, and Shippers' issued by the Board of Trade in September 1907, but the magnitude of the risks involved in the treatment of this material, and the need for more stringent regulations, was strikingly demonstrated by the death of five Russian immigrants on board the s.s. 'Ashton' in December 1908, during this ship's voyage from Antwerp to Grimsby. Inquiries made on behalf of the Local Government Board into this occurrence brought to light a number of previous accidents in connection with the transport of ferro-silicon, and after conference with the Home Office and the Board of Trade the full investigation of the subject was entrusted to Dr. Copeman, with whom subsequently Mr. S. R. Bennett, one of H.M. Inspectors of Factories, and Dr. Wilson Hake, Lecturer on Chemistry at Westminster Hospital, collaborated.

Among the accidents known to have occurred from the handling or transport of ferro-silicon may be mentioned the explosion of consignments enclosed in iron drums, the ferro-silicon in which contained about 54 or 55 per cent. of silicon. But more important and much more frequent than these are the well-authenticated cases of sudden illness and death caused by the gases evolved from certain cargoes of ferro-silicon, full details of which are set out in an official report recently presented to both Houses of Parliament.

Low-grade ferro-silicon—*i.e.*, an alloy containing not more than 15 per cent. of silicon—is made in blast furnaces to a considerable extent in this country; but the high-grade variety, containing from 25 to 95 per cent. of silicon, can only be produced at the high temperatures attainable in the electric furnace. The latter variety is imported from certain districts in France, and, to a less extent, from Austria, Scandinavia, &c., where ample electrical energy is derivable at a low cost from water power. About 4,000 tons of this material are said, to be imported annually into England, and, as serious inconvenience to steel manufacturers is being caused by the refusal of shipping firms to carry it, there is great need for regulations permitting its transport under defined conditions which will obviate accident.

The electrically produced or high-grade ferro-silicon has in recent years displaced in large measure the blast-furnace variety in the manufacture of the better qualities of steel, and as an outcome of this change the dangers of noxious fumes from the high-grade variety have gradually been realised. Manufacturers and chemists, in the light of their special experience, have come to the conclusion that it is solely or chiefly the 50 per cent. variety of the high-grade material which is thus dangerous. But that the matter is in reality considerably more complicated is indicated by the results of Dr. Hake's chemical researches. It should, however, be added that some of the firms concerned have recognised the importance of porosity and liability to disintegrate as factors in the ready evolution of poisonous fumes, and the French Commission draw attention, in their report, to the safety of compact alloys. It is evident, however, that at present, unless and until sharp lines can be drawn between the different amounts of gas evolved from different samples of ferro-silicon under similar circumstances, it is impracticable with certainty to distinguish, among any of the higher percentage varieties of ferro-silicon, between safety and danger. Nevertheless the recommendations suggested by the writer, and now officially adopted by the Board of Trade, will probably prevent the occurrence of future accidents in the transport of ferro-silicon. They comprise the need for ascertaining that

the ferro-silicon has been broken into pieces of the size in which it is usually sold some time before being taken on board ship; the marking in bold letters of the certified percentage grade of each consignment on the barrel or other receptacle, and the date of manufacture; the prohibition of conveyance of ferro-silicon on passenger vessels; and the adoption of certain precautions during transport in cargo boats.

7. *The Corrosion of Iron and Steel.* *By* J. NEWTON FRIEND.

During the last few years the consumption of iron for structural purposes has largely increased. New steel bridges are being constantly erected, and reinforced concrete is now meeting with an ever-increasing demand. Unfortunately, however, iron is very liable to decay through corrosion, and the loss entailed thereby is enormous; for not only must our new structures be built more solidly than would otherwise be necessary, but many of our old structures have to be rebuilt with fresh metal, which is both costly and wasteful.

The importance of understanding the underlying causes of corrosion can therefore be scarcely exaggerated. Two rival theories have been suggested. The one, known as the electrolytic theory, assumes that pure oxygen (or air) and pure liquid water *alone* are necessary to effect the rusting of pure iron. According to the acid theory, however, such is not the case, the presence of at least traces of an acid, either free or combined with a base, being essential to corrosion.

Hitherto no investigator has succeeded in devising an apparatus, absolutely free from objection, by means of which a decision could be arrived at between these two rival theories. The author, however, described a simple form of apparatus by means of which the correctness of the acid theory is established. [A diagram of the apparatus is given in the Proceedings of the Chemical Society, June 16, 1910.]

A small steel cylinder is closed at one end, the open end being plugged with an indiarubber bung, through which two glass tubes pass in such a manner that cold water can be circulated through them, and thus keep the steel cylinder cool. The whole is now suspended in a flask and securely fixed in position by an indiarubber bung, which closes the mouth of the flask. This latter contains about 100 c.c. (*i.e.*, 3 oz.) of strong caustic potash solution, and the pressure of the air inside is reduced to about half an atmosphere. On placing the flask in a water-bath at 100° C. some pure water distils from the potash solution in a constant stream on the steel cylinder, and drips off, thus washing it entirely free from alkali. After a few hours we thus have pure air, pure water, and steel in contact, but no rusting occurs.

If the alkali is replaced by water, however, rusting occurs with great vigour in a very short time, owing to the presence of traces of carbon dioxide and other acid vapours normally occurring in distilled water and the atmosphere of a laboratory.

8. *The Influence of Heat Treatment on the Corrosion, Solubility, and Solution Pressures of Steel.* *By* CYRIL CHAPPELL *and* FRANK HODSON.

The authors decided to conduct a research on the above lines, as no previous work has dealt with the influence of heat treatment on the corrodibility of steel in a solution like sea-water. They also wished to obtain some definite data as to whether the solubility of steel in dilute sulphuric acid is a correct measure of its liability to corrosion in sea-water.

The steels used were commercial Bessemer steels of ascending carbon percentage (supplied by Professor McWilliam), and standard pieces were subjected to the following typical heat treatments: hardening, normalising, rolling, and annealing.

Two types of test were carried out:—

(*a*) Simple Corrosion.—The loss in weight was determined after immersion in sea-water, out of contact with any other metal, for 28, 56, and 112 days respectively.

(*b*) Galvanic Corrosion.—This was tested in sea-water in galvanic connection

with Swedish bar iron. The E.M.F. between the two metals was accurately determined by a galvanometer. This test is really, therefore, a modified solution pressure-test, and was employed by Andrews in his standard researches on corrosion.

The simple corrosion results show that an annealed steel is least liable to corrosion and hardened steels most liable. A general increase in corrodibility is noticed with an increase of carbon percentage in steel.

The galvanic corrosion results show that when a steel is in contact with pure iron the corrodibility (as indicated by strength and direction of current) is in the following increasing order: Hardened, rolled, normalised, annealed.

Solubility tests were determined in one and two per cent. sulphuric acid for 72 hours, each strength of acid giving similar types of curve.

These results show to a marked degree the influence of both *heat treatment* and *composition*. The relative position of the curves are, however, in exactly the reverse order from that found in the case of simple corrosion which would not be the case if solubility in acid were merely an accelerated corrosion test. The special feature of the solubility curves is the point at 45 per cent. carbon (which is also slightly marked in the corrodibility curves), and which has been previously noted by Messrs. Heyn and Bauer.

The solution pressure of each steel was separately determined in each of the three following solutions: Sea-water, one per cent. sulphuric acid, and slightly acidulated N/10 ferrous sulphate solution. The influence of heat treatment is in each case very marked, the effect produced being practically the same in every case, the annealed and rolled steels having the highest solution pressures, the normalised intermediate, and the hardened steels the lowest values.

A comparison of the corrodibility and solubility curves indicates, in the first place, that the solubility results cannot be accepted as indicative of the relative corrodibilities of the steels in such solutions as sea-water, whereas, for example, an annealed steel is much more soluble in dilute sulphuric acid than the same steel in the hardened condition; yet, when subjected to a simple corrosion test in sea-water the hardened steel is found, on the contrary, to corrode much more than the annealed steel. So that although a dilute acid test is of value for certain purposes, yet these results show it to be unreliable as a guide to the corrodibility of steel in such solutions as sea-water.

The general influence of heat treatment on the various properties examined is found to be the same in the case of solubility, solution pressure (in all three solutions), and the galvanic corrosion results. In the simple corrosion results, however, treatment exerts practically the opposite effect to that found in above-mentioned tests.

The results obtained suggest the probability that the solution pressure is the governing factor in the solubility of steel in dilute sulphuric acid, its influence being modified by auto-electrolytic actions due to constituents and stresses (set up by treatment) in the steel. Consideration of simple corrosion results suggests that the solution pressure only plays a secondary part in corrosion, the principal factor being the auto-electrolytic action in the steel itself.

Marked breaks in the continuity of the curves appear in every case at about 0·3 per cent. and 0·75 per cent. carbon; the latter break suggests the likelihood of another peak having its maximum at the saturation point of the steel. We cannot at present account for the break at 0·3 per cent. carbon, but further work is intended on the influence of carbon and other elements on corrosion, which we anticipate will elucidate this matter.

Although heat treatment exerts considerable influence on corrosion, it cannot be expected to make up for the defects due to segregation or inferior material.

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9. *The Crystalline Structure of Iron at High Temperatures.* *By* Walter Rosenhain, *B.A., D.Sc.*

The immediate object of the experiments was to study the mode of deformation of iron and steel under stresses applied to the metal at high temperatures. The principal questions to be decided were, whether at high temperatures the mode of deformation was still of a strictly crystalline character, such as that

which has been observed at ordinary temperatures, and whether the allotropic transformations of iron affect its behaviour under strain. The method of Ewing and Rosenhain for observing the effects of strain on metals consists in preparing a properly polished surface on a specimen of suitable shape, and subsequently exposing the specimen to plastic deformation, the changes in the microscopic features of the surface being studied during, and more especially after, the application of the strain. In order to apply this method to hot metal it was necessary to devise means for heating the specimens in such a manner that even at temperatures well above 1000° C. the original polished surface would remain free from oxidation. The method adopted was that of heating the specimen electrically in a very high vacuum, and in this way specimens could be heated up to 1100° C. without injury to the surfaces. For the purpose of applying the desired strain to the specimen while heated *in vacuo*, an apparatus was devised whereby a compressed spring could be released at any desired moment by electrically fusing a wire which had kept the spring compressed; by means of a suitably arranged lever the release of this spring was caused to strain the specimen to any desired extent, while the operation could take place when the specimen had attained any desired temperature. The actual temperature of the specimen was determined by attaching to the rear or unpolished side minute particles of various salts of known fusion points and observing which of them had melted. The specimens used in this apparatus were thin, short strips of sheet metal, and as these were heated by a direct electric current passing through them, the ends of the specimen remained a good deal colder than the middle, owing to the conduction of heat from these ends into the comparatively massive frame of the apparatus. In this way strain was applied to a strip of metal varying continuously in temperature from the middle towards each end.

The material used for the earlier experiments was a pure variety of very mild steel such as that employed for transformer-sheets, but this had been annealed in hydrogen in order to remove all traces of oxide. Subsequently other materials—all of them approximating in composition to pure iron—were employed, notably some specially prepared electrolytic iron of a very high degree of purity. The photo-micrographs accompanying the paper showed that the behaviour of these different materials was closely similar.

Before describing the effects of strain, the effects of simple heating *in vacuo* must be considered, since this alone produces changes in the surface appearance. Those portions heated up to the Ac_2 point (770° C. in one of the materials used) show no changes; those portions which had attained a temperature between Ac_2 and Ac_1 (941° C. in one of the materials) show a double system of boundaries due to the volume-change which iron undergoes on passing through the change from the α to the β state. Those parts of the specimen which had been heated above Ac_1 showed, particularly in cases where the vacuum had not been as high as possible, a slight amount of tinting due to oxidation, and this revealed a third structure superposed on the β structure just mentioned and (in the case of etched specimens) on the original α structure. This last, which is the structure of γ iron, shows the characteristic twinned structure of this material.

The effects of strain indicated the three regions of temperature corresponding to the three allotropic forms of iron in a very definite manner. In the region of α iron observation shows that on passing along the specimen in the direction of increasing temperature the amount of deformation, as evidenced by the number and depth of the slip-bands formed, increases steadily, but the slip-bands retain the curved and forked appearance characteristic of α iron. The amount of deformation increases rapidly with increasing temperature until at a point of the specimen coinciding with the α/β transformation, the signs of deformation cease quite abruptly. For a short length of the specimen there are no slip-bands, and the material appears to have undergone no plastic deformation. On passing to still hotter portions of the specimen, slip-bands again appear, and when the region of γ iron is reached the bands again become numerous, but now show the regular, rectilinear character and the characteristic features of twinned crystals, thus differing very strikingly from the slip-bands seen in α iron.

The conclusions drawn from the observations here indicated are:—

1. That iron at temperatures up to 1100° C. behaves as a crystalline aggregate and undergoes plastic deformation by a process of slip on the cleavage or gliding

planes of its constituent crystal; this may or may not be accompanied by mechanical twinning.

2. That iron between the ordinary temperature and 1,000° C. exists in three distinct modifications possessing widely different mechanical properties, and that the temperature-ranges in which these modifications exist are consistent with the identification of these three modifications with the α, β, and γ forms of iron, according to the allotropic theory of Osmond and Roberts-Austen.

3. That β iron, although existing at a higher temperature, is markedly stronger and harder than α iron, and that the α/β transformation involves a volume-change.

4. That γ iron as found in approximately pure iron at high temperatures possesses the characteristic structure and some of the properties of 'γ iron' as found in certain alloy steels.

Incidentally, the demonstration of the real existence of a hard β modification of iron at high temperatures serves to prove the correctness of the contention that the failure to harden pure iron by quenching is due to the difficulty of inhibiting the $\beta = \alpha$ transformation by rapid cooling, except in the presence of carbon. The observed power of β iron to resist deformation at 800° C. under a stress which is sufficient to fracture the same section of α iron at a temperature of 750° C., taken together with the powerful softening effect of a rise of temperature of 750°, serves to indicate that if β iron could be preserved in existence at the ordinary temperature, it would possess a very high degree of hardness and strength, probably quite comparable with that of hardened steel.

10. *Report on Electroanalysis.*—See Reports, p. 79.

SECOND DIVISION.

The following Papers and Reports were read :—

1. *An Instance illustrating the Relative Instabilities of the Trimethylene Ring as compared with the Tetramethylene Ring. By* Dr. J. F. THORPE, *F.R.S.*

2. *The Elimination of a Carboxethyl Group during the Closing of the Five-Membered Ring. By* A. D. MITCHELL *and* Dr. J. F. THORPE, *F.R.S.*

3. *The Molecular Complexity of Nitrosoamines. By* W. E. S. TURNER *and* E. W. MERRY.

The aliphatic nitro compounds are known to exist in the liquid condition in a complex molecular condition, and it was an interesting question whether this property of giving rise to molecular complexes was shared by the nitroso compounds. The high dielectric constant of dimethylnitrosoamine suggests the probability that this substance was a molecularly complex one.

Measurements were made of the surface energy of three nitrosoamines, the results showing that the aliphatic nitrosoamines are associated liquids, whilst the aromatic compounds, like the aromatic nitrites and nitro compounds, are non-associated.

The association in dimethylnitrosoamine is very much less than that in acetamide, a substance whose dielectric constant is very little higher than that of the nitrosoamine.

4. *Molecular Association in Water, illustrated by Substances containing the Hydroxyl Group. By* W. E. S. TURNER *and* C. J. PEDDLE.

Until the recent work of Meldrum and Turner on the molecular weights of amides in water, the fact that molecular association may occur in aqueous

solution had not been generally recognised. Indeed, such association is hardly to be expected on account of the high dielectric constant of water.

The authors have found molecular association in water to be quite extensive among aromatic substances. Benzoic acid, for example, is associated in water even to a greater extent than in benzene.

The view suggested by Meldrum and Turner, that the association in water may be accounted for by supposing the molecular complexes to undergo dissociation, is borne out by the results now obtained in water and by others in ethyl alcohol as solvent, in which normal substances, such as benzyl and diphenylamine, are apparently associated.

5. *The Problem of Molecular Association : I. The Affinities of the Halogen Elements. By* W. E. S. TURNER.

The author undertook a criticism of Abegg's and other recent theories of valency, in so far as these theories attempt to account for molecular association and for the existence of and formation of molecular compounds. The paper embodied the results of the determination, in solution, of the molecular weights of fifty to sixty halogen-containing substances of different types, the examination of mixtures of such halogen compounds, and of iodine and these compounds, and included a review of the molecular weights of all types of halogen-containing bodies.

It was shown that molecular association occurs only when the halogen compound is an electrolyte, that there is no special virtue in the halogen elements—such as the existence of a large number of contra or residual valencies—neither is there any virtue in the halogen ion differentiating it from other ions. Thus it was shown that, in neutral solvents, nitrates are strongly associated.

Throughout it was demonstrated that molecular association in neutral solvents is the reciprocal of the supposed electrolytic dissociation in the dissociating solvents. The question of the origin of the electrical forces which appear on 'ionisation' was also raised.

Formation of molecular compounds was shown, except possibly in the case of the periodides, not to be due to the same forces which bring about molecular association in an individual substance.

Lastly, the parallel which exists between the extent of association and the conducting power in a solvent was shown to be a close one in the case of the halogen-containing substances.

6. *Formation of Tolane Derivatives from Benzotrichlorides. By* DR. J. KENNER *and* E. WITHAM.

7. *The Nitro Chloro and the Dichlorotoluene Sulphonic Acids. By* Dr. J. KENNER *and* Professor W. P. WYNNE, *F.R.S.*

8. *The Action of Metals upon Alcohols. By* Dr. F. M. PERKIN.

9. *Report on Dynamic Isomerism.*—See Reports, p. 80.

10. *Report on Aromatic Nitroamines.*—See Reports, p. 82.

11. *Report on the Study of Isomorphous Sulphonic Derivatives of Benzene.*—See Reports, p. 100.

12. *Report on the Study of Hydroaromatic Substances.*—See Reports, p. 82.

SUB-SECTION OF AGRICULTURE.

Chairman. A. D. Hall, M.A., F.R.S.

THURSDAY, SEPTEMBER 1.

The Chairman delivered the following Address :—

I believe it is customary for anyone who has the honour of presiding over a section of the British Association to provide in his presidential address either a review of the current progress of his subject or an account of some large piece of investigation by which he himself has illuminated it. I wish I had anything of the latter kind which I could consider worthy to occupy your attention for the time at my disposal; and as to a review of the subject, I am not without hopes that the sectional meetings themselves will provide all that is necessary in the way of a general review of what is going forward in our department of science. I have, therefore, chosen instead to deal from an historic point of view with the opinions which have prevailed about one central fact, and I propose to set before you this morning an account of the ebb and flow of ideas as to the causes of the fertility of the soil, a question which has naturally occupied the attention of everyone who has exercised his reason upon matters connected with agriculture. The fertility of the soil is perhaps a vague title, but by it I intend to signify the greater or less power which a piece of land possesses of producing crops under cultivation, or, again, the causes which make one piece of land yield large crops when another piece alongside only yields small ones, differences which are so real that a farmer will pay three or even four pounds an acre rent for some land, whereas he will regard other as dear at ten shillings an acre.

If we go back to the seventeenth century, which we may take as the beginning of organised science, we shall find that men were concerned with two aspects of the question—how the plant itself gains its increase in size, and, secondly, what the soil does towards supplying the material constituting the plant. The first experiment we have recorded is that of Van Helmont, who placed 200 lb. of dried earth in a tub, and planted therein a willow tree weighing 5 lb. After five years the willow tree weighed 169 lb. 3 oz., whereas the soil when redried had lost but 2 oz., though the surface had been carefully protected meantime with a cover of tin. Van Helmont concluded that he had demonstrated a transformation of water into the material of the tree. Boyle repeated these experiments, growing pumpkins and cucumbers in weighed earth and obtaining similar results, except when his gardener lost the figures, an experience that has been repeated. Boyle also distilled his pumpkins, &c., and obtained therefrom various tars and oils, charcoal and ash, from which he concluded that a real transmutation had been effected, 'that salt, spirit, earth, and even oil (though that be thought of all bodies the most opposite to water) may be produced out of water.'

There were not, however, wanting among Boyle's contemporaries men who pointed out that spring water used for the growing plants in these experiments contained abundance of dissolved material, but in the then state of chemistry the discussion as to the origin of the carbonaceous material in the plant could only be verbal. Boyle himself does not appear to have given any consideration to the part played by the soil in the nutrition of plants, but among his contemporaries experiment was not lacking. Some instinct seems to have led them to regard nitre as one of the sources of fertility, and we find that Sir Kenelm Digby, at Gresham College in 1660, at a meeting of the Society for Promoting Philosophical Knowledge by Experiment, in a lecture on the vegetation of plants, describes an experiment in which he watered young barley plants with a weak solution of nitre and found that their growth was promoted thereby; and John Mayow, that brilliant Oxford man whose early death cost so much to the young science of chemistry, went even further, for, after discussing the growth of nitre in soils, he pointed out that it must be this salt which feeds the plant, because none is to be extracted from soils in which plants are growing. So general

has this association of nitre with the fertility of soils become that in 1675 John Evelyn writes: 'I firmly believe that where saltpetre can be obtained in plenty we should not need to find other composts to ameliorate our ground'; and Henshaw, of University College, one of the first members of the Royal Society, also writes about saltpetre: 'I am convinced indeed that the salt which is found in vegetables and animals is but the nitre which is so universally diffused through all the elements (and must therefore make the chief ingredient in their nutriment, and by consequence all their generation,) a little altered from its first complexion.'

But these promising beginnings of the theory of plant nutrition came to no fruition; the Oxford movement in the seventeenth century was but the false dawn of science. At its close the human mind, which had looked out of doors for some relief from the fierce religious controversy with which it had been so long engrossed, turned indoors again and went to sleep for another century. Mayow's work was forgotten, and it was not until Priestley and Lavoisier, De Saussure, and others, about the beginning of the nineteenth century, arrived at a sound idea of what the air is and does that it became possible to build afresh a sound theory of the nutrition of the plant. At this time the attention of those who thought about the soil was chiefly fixed upon the humus. It was obvious that any rich soils, such as old gardens and the valuable alluvial lands, contained large quantities of organic matter, and it became somewhat natural to associate the excellence of these fat, unctuous soils with the organic matter they contained. It was recognised that the main part of a plant consisted of carbon, so that the deduction seemed obvious that the soils rich in carbon yielded those fatty, oily substances which we now call humus to the plant, and that their richness depended upon how much of such material they had at their disposal. But by about 1840 it had been definitely settled what the plant is composed of and whence it derives its nutriment—the carbon compounds which constitute nine-tenths of the dry weight from the air, the nitrogen, and the ash from the soil. Little as he had contributed to the discovery, Liebig's brilliant expositions and the weight of his authority had driven this broad theory of plant nutrition home to men's minds; a science of agricultural chemistry had been founded, and such questions as the function of the soil with regard to the plant could be studied with some prospect of success. By this time also methods of analysis had been so far improved that some quantitative idea could be obtained as to what is present in soil and plant, and, naturally enough, the first theory to be framed was that the soil's fertility was determined by its content of those materials which are taken from it by the crop. As the supply of air from which the plant derives its carbonaceous substance is unlimited, the extent of growth would seem to depend upon the supply available of the other constituents which have to be provided by the soil. It was Daubeny, Professor of Botany and Rural Economy at Oxford, and the real founder of a science of agriculture in this country, who first pointed out the enormous difference between the amount of plant food in the soil and that taken out by the crop. In a paper published in the 'Philosophical Transactions' in 1845, being the Bakerian Lecture for that year, Daubeny described a long series of experiments that he had carried out in the Botanic Garden at Oxford, wherein he cultivated various plants, some grown continuously on the same plot and others in a rotation. Afterwards he compared the amount of plant food removed by the crops with that remaining in the soil. Daubeny obtained the results with which we are now familiar, that any normal soil contains the material for from fifty to a hundred field crops. If, then, the growth of the plant depends upon the amount of this material it can get from the soil, why is that growth so limited, and why should it be increased by the supply of manure, which only adds a trifle to the vast stores of plant food already in the soil? For example, a turnip crop will only take away about 30 lb. per acre of phosphoric acid from a soil which may contain about 3,000 lb. an acre; yet, unless to the soil about 50 lb. of phosphoric acid in the shape of manure is added, hardly any turnips at all will be grown. Daubeny then arrived at the idea of a distinction between the active and dormant plant food in the soil. The chief stock of these materials, he concluded, was combined in the soil in some form that kept it from the plant, and only a small proportion from time to time became soluble and available for food,

He took a further step, and attempted to determine the proportion of the plant food which can be regarded as active. He argued that since plants only take in materials in a dissolved form, and as the great natural solvent is water percolating through the soil more or less charged with carbon dioxide, therefore in water charged with carbon dioxide he would find a solvent which would extract out of a soil just that material which can be regarded as active and available for the plant. In this way he attacked his Botanic Garden soils and compared the materials so dissolved with the amount taken away by his crops. The results, however, were inconclusive and did not hold out much hope that the fertility of the soil could be measured by the amount of available plant food so determined. Daubeny's paper was forgotten, but exactly the same line of argument was revived again about twenty years ago, and all over the world investigators began to try to measure the fertility of the soil by determining as 'available' plant food the phosphoric acid and potash that could be extracted by some weak acid. A large number of different acids were tried, and although a dilute solution of citric acid is at present the most generally accepted solvent I am still of opinion that we shall come back to the water charged with carbon dioxide as the only solvent of its kind for which any justification can be found. Whatever solvent, however, is employed to extract from the soil its available plant food, the results fail to determine the fertility of the soil, because we are measuring but one of the factors in plant production, and that often a comparatively minor one. In fact, some investigators—Whitney and his colleagues in the American Department of Agriculture—have gone so far as to suppose that the actual amount of plant food in the soil is a matter of indifference. They argue that as a plant feeds upon the soil water, and as that soil water must be equally saturated with, say, phosphoric acid, whether the soil contains 1,000 lb. or 3,000 lb. per acre of the comparatively insoluble calcium and iron salts of phosphoric acid which occur in the soil, the plant must be under equal conditions as regards phosphoric acid whatever the soil in which it may be grown. This argument is, however, a little more suited to controversy than to real life; it is too fiercely logical for the things themselves and depends upon various assumptions holding rigorously, whereas we have more reason to believe that they are only imperfect approximations to the truth. Still this view does merit our careful attention, because it insists that the chief factor in plant production must be the supply of water to the plant, and that soils differ from one another far more in their ability to maintain a good supply of water than in the amount of plant food they contain. Even in a climate like our own, which the textbooks describe as 'humid' and we are apt to call 'wet,' the magnitude of our crops is more often limited by want of water than by any other single factor. The same American investigators have more recently engrafted on to their theory another supposition, that the fertility of soil is often determined by excretions from the plants themselves, which thereby poison the land for a renewed growth of the same crop, though the toxin may be harmless to a different plant which follows it in the rotation. This theory had also been examined by Daubeny, and the arguments he advanced against it in 1845 are valid to this day. Schreiner has indeed isolated a number of organic substances from soils—di-hydroxystearic acid and picoline-carboxylic acid were the first examples—which he claims to be the products of plant growth and toxic to the further growth of the same plants. The evidence of toxicity as determined by water-cultures requires, however, the greatest care in interpretation, and it is very doubtful how far it can be applied to soils with their great power of precipitating or otherwise putting out of action soluble substances with which they may be supplied. Moreover, there are as yet no data to show whether these so-called toxic substances are not normal products of bacterial action upon organic residues in the soil, and as such just as abundant in fertile soils rich in organic matter as in the supposed sterile soils from which they were extracted.

As then we have failed to base a theory of fertility on the plant food that we can trace in the soil by analysis let us come back to Mayow and Digby and consider again the nitre in the soil, how it is formed and how renewed. Their views of the value of nitrates to the plant were justified when the systematic study of plant-nutrition began, and demonstrated that plants can only obtain their supply of the indispensable element nitrogen when it is presented in the form of a nitrate,

but it was not until within the last thirty years that we obtained an idea as to how the nitre came to be found. The oxidation of ammonia and other organic compounds of nitrogen to the state of nitrate was one of the first actions in the soil which was proved to be brought about by bacteria, and by the work of Schloesing and Müntz, Warington, and Winogradsky we learnt that in all cultivated soils two groups of bacteria exist which successively oxidise ammonia to nitrites and nitrates, in which latter state the nitrogen is available for the plant. These same investigators showed that the rate at which nitrification takes place is largely dependent upon operations under the control of the farmer: the more thorough the cultivation, the better the drainage and aëration, and the higher the temperature of the soil the more rapidly will the nitrates be produced. As it was then considered that the plant could only assimilate nitrogen in the form of nitrates, and as nitrogen is the prime element necessary to nutrition, it was then an easy step to regard the fertility of the soil as determined by the rate at which it would give rise to nitrates. Thus the bacteria of nitrification became regarded as a factor, and a very large factor, in fertility. This new view of the importance of the living organisms contained in the soil further explained the value of the surface soil, and demolished the fallacy which leads people instinctively to regard the good soil as lying deep and requiring to be brought to the surface by the labour of the cultivator. This confusion between mining and agriculture probably originated in the quasi-moral idea that the more work you do the better the result will be; but its application to practice with the aid of a steam plough in the days before bacteria were thought of ruined some of the clay soils of the Midlands for the next half-century. Not only is the subsoil deficient in humus, which is the accumulated *débris* of previous applications of manure and vegetation, but the humus is the home of the bacteria which have so much to do with fertility.

The discovery of nitrification was only the first step in the elucidation of many actions in the soil depending upon bacteria—for example, the fixation of nitrogen itself. A supply of combined nitrogen in some form or other is absolutely indispensable to plants and, in their turn, to animals; yet, though we live in contact with a vast reservoir of free nitrogen gas in the shape of the atmosphere, until comparatively recently we knew of no natural process except the lightning flash which would bring such nitrogen into combination. Plants take combined nitrogen from the soil, and either give it back again or pass it on to animals. The process, however, is only a cyclic one, and neither plants nor animals are able to bring in fresh material into the account. As the world must have started with all its nitrogen in the form of gas it was difficult to see how the initial stock of combined nitrogen could have arisen; for that reason many of the earlier investigators laboured to demonstrate that plants themselves were capable of fixing and bringing into combination the free gas in the atmosphere. In this demonstration they failed, though they brought to light a number of facts which were impossible to explain and only became cleared up when, in 1886, Hellreigel and Wilfarth showed that certain bacteria, which exist upon the roots of leguminous plants, like clover and beans, are capable of drawing nitrogen from the atmosphere. Thus they not only feed the plant on which they live, but they actually enrich the soil for future crops by the nitrogen they leave behind in the roots and stubble of the leguminous crop. Long before this discovery experience had taught farmers the very special value of these leguminous crops; the Roman farmer was well aware of their enriching action, which is enshrined in the well-known words in the Georgics beginning, 'Aut ibi flava seres,' where Virgil says that the wheat grows best where before the bean, the slender vetch, or the bitter lupin had been most luxuriant. Since the discovery of the nitrogen-fixing organisms associated with leguminous plants other species have been found resident in the soil which are capable of gathering combined nitrogen without the assistance of any host plant, provided only they are supplied with carbonaceous material as a source of energy whereby to effect the combination of the nitrogen. To one of these organisms we may with some confidence attribute the accumulation of the vast stores of combined nitrogen contained in the black virgin soils of places like Manitoba and the Russian steppes. At Rothamsted we have found that the plot on the permanent wheat field which never receives any manure has been losing nitrogen at a rate which almost exactly represents the differences between the annual removal of the crop and the receipts of combined nitrogen in the rain. We

can further postulate only a very small fixation of nitrogen to balance the other comparatively small losses in the drainage water or in the weeds that are removed; but on a neighbouring plot which has been left waste for the last quarter of a century, so that the annual vegetation of grass and other herbage falls back to the soil, there has been an accumulation of nitrogen representing the annual fixation of nearly a hundred pounds per acre. The fixation by the *azotobacter* has been possible on this plot, because there alone does the soil receive a supply of carbohydrate, by the combustion in which the *azotobacter* obtained the energy necessary to bring the nitrogen into combination. On the unmanured plot the crop is so largely removed that the little root and stubble remaining does not provide material for much fixation.

Though numerous attempts have been made to correlate the fertility of the soil with the numbers of this or that bacterium existing therein, no general success has been attained, because probably we measure a factor which is only on occasion the determining factor in the production of the crop. Meantime our sense of the complexity of the actions going on in the soil has been sharpened by the discovery of another factor, affecting in the first place the bacterial flora in the soil and, as a consequence, its fertility. Ever since the existence of bacteria has been recognised attempts have been made to obtain soils in a sterile condition, and observations have been from time to time recorded to the effect that soil which has been heated to the temperature of boiling water, in order to destroy any bacteria it may contain, had thereby gained greatly in fertility, as though some large addition of fertiliser had been made to it. Though these observations have been repeated in various times and places they were generally ignored, because of the difficulty of forming any explanation : a fact is not a fact until it fits into a theory. Not only is sterilisation by heating thus effective, but other antiseptics, like chloroform and carbon bisulphide vapour, give rise to a similar result. For example, you will remember how the vineyards of Europe were devastated some thirty years ago by the attacks of phylloxera, and though in a general way the disease has been conquered by the introduction of a hardy American vine stock which resists the attack of the insect, in many of the finest vineyards the owners have feared to risk any possible change in the quality of the grape through the introduction of the new stock, and have resorted instead to a system of killing the parasite by injecting carbon bisulphide into the soil. An Alsatian vinegrower who had treated his vineyards by this method observed that an increase of crop followed the treatment even in cases where no attack of phylloxera was in question. Other observations of a similar character were also reported, and within the last five years the subject has received some considerable attention until the facts became established beyond question. Approximately the crop becomes doubled if the soil has first been heated to a temperature of 70° to 100° for two hours, while treatment for forty-eight hours with the vapour of toluene, chloroform, &c., followed by a complete volatilisation of the antiseptic, brings about an increase of 30 per cent. or so. Moreover, when the material so grown is analysed, the plants are found to have taken very much larger quantities of nitrogen and other plant foods from the treated soil; hence the increase of growth must be due to larger nutriment and not to mere stimulus. The explanation, however, remained in doubt until it has been recently cleared up by Drs. Russell and Hutchinson, working in the Rothamsted laboratory. In the first place, they found that the soil which had been put through the treatment was chemically characterised by an exceptional accumulation of ammonia, to an extent that would account for the increased fertility. At the same time it was also found that the treatment did not affect complete sterilisation of the soil, though it caused at the outset a great reduction in the numbers of bacteria present. This reduction was only temporary, for as soon as the soil was watered and left to itself the bacteria increased to a degree that is never attained under normal conditions. For example, one of the Rothamsted soils employed contains normally about seven million bacteria per gram—a number which remains comparatively constant under ordinary conditions. Heating reduced the numbers to 400 per gram, but four days later they had risen to six million, after which they increased to over forty million per gram. When the soil was treated with toluene a similar variation in the number of bacteria was observed. The accumulation of ammonia in the treated soils was accounted for by this increase

in the number of bacteria, because the two processes went on at about the same rate. Some rearrangements were effected also in the nature of the bacterial flora; for example, the group causing nitrification was eliminated, though no substantial change was effected in the distribution of the other types. The bacteria which remained were chiefly of the class which split up organic nitrogen compounds into ammonia, and as the nitrate-making organisms which normally transform ammonia in the soil as fast as it is produced had been killed off by the treatment, it was possible for the ammonia to accumulate. The question now remaining was, What had given this tremendous stimulus to the multiplication of the ammonia-making bacteria? and by various steps, which need not here be enumerated, the two investigators reached the conclusion that the cause was not to be sought in any stimulus supplied by the heating process, but that the normal soil contained some negative factor which limited the multiplication of the bacteria therein. Examination along these lines then showed that all soils contain unsuspected groups of large organisms of the protozoa class, which feed upon living bacteria. These are killed off by heating or treatment by antiseptics, and on their removal the bacteria, which partially escape the treatment and are now relieved from attack, increase to the enormous degree that we have specified According to this theory the fertility of a soil containing a given store of nitrogen compounds is limited by the rate at which these nitrogen compounds can be converted into ammonia, which, in its turn, depends upon the number of bacteria present effecting the change, and these numbers are kept down by the larger organisms preying upon the bacteria. The larger organisms can be removed by suitable treatment, whereupon a new level of ammonia-production, and therefore of fertility, is rapidly attained. Curiously enough one of the most striking of the larger organisms is an amœba akin to the white corpuscles of the blood—the phagocytes, which, according to Metchnikoff's theory, preserve us from fever and inflammation by devouring such intrusive bacteria as find entrance in the blood. The two cases are, however, reversed: in the blood the bacteria are deadly, and the amœba therefore beneficial, whereas in the soil the bacteria are indispensable and the amœba become noxious beasts of prey.

Since the publication of these views of the functions of protozoa in the soil confirmatory evidence has been derived from various sources. For example, men who grow cucumbers, tomatoes, and other plants under glass are accustomed to make up extremely rich soils for the intensive culture they practise, but, despite the enormous amount of manure they employ, they find it impossible to use the same soil for more than two years. Then they are compelled to introduce soil newly taken from a field and enriched with fresh manure. Several of these growers here have observed that a good baking of this used soil restores its value again; in fact, it becomes too rich and begins to supply the plant with an excessive amount of nitrogen. It has also been pointed out that it was the custom of certain of the Bombay tribes to burn vegetable rubbish mixed as far as possible with the surface soil before sowing their crop, and the value of this practice in European agriculture, though forgotten, is still on record in the books on Roman agriculture. We can go back to the Georgics again, and there find an account of a method of heating the soil before sowing, which has only received its explanation within the last year, but which in some form or other has got to find its way back again into the routine of agriculture. Indeed, I am informed that one of the early mysteries, many of which we know to be bound up with the practices of agriculture, culminated in a process of firing the soil, preparatory to sowing the crop.

My time has run out, and I fear that the longer I go on the less you will feel that I am presenting you with any solution of the problem with which we set out—'What is the cause of the fertility of the soil?' Evidently there is no simple solution; there is no single factor to which we can point as *the* cause; instead we have indicated a number of factors any one of which may at a given time become a limiting factor and determine the growth of the plant. All that science can do as yet is to ascertain the existence of these factors one by one and bring them successively under control; but, though we have been able to increase production in various directions, we are still far from being able to disentangle all the interacting forces whose resultant is represented by the crop.

One other point, I trust, my sketch may have suggested to you : when science, a child of barely a century's growth, comes to deal with a fundamental art like agriculture, which goes back to the dawn of the race, it should begin humbly by accepting and trying to interpret the long chain of tradition. It is unsafe for science to be dogmatic; the principles upon which it relies for its conclusions are often no more than first approximations to the truth, and the want of parallelism, which can be neglected in the laboratory, gives rise to wide divergencies when introduced into the rgions of practice. The method of science is, after all, only an extension of experience. What I have endeavoured to show in my address is the continuous thread which links the traditional practices of agriculture with the most modern developments of science.

The following Papers were then read :—

1. *Impurities in the Atmosphere of Towns and their Effects upon Vegetation. By* Arthur G. Ruston, *B.A., B.Sc., and* Charles Crowther, *M.A., Ph.D.*

The atmospheric impurities in different parts of the city of Leeds have been investigated by collecting samples of rain for a period of twelve months (November 1907 to October 1908). Similar results are given for the rainfall at the Manor Farm, Garforth, about seven and a half miles due east of the main industrial quarter of Leeds. The samples were collected with funnels twelve inches in diameter, and were representative of the whole of the atmospheric impurities, both soluble and insoluble, whether actually brought down by the rain or deposited at other times. The estimations made with the samples are indicated in the following table :—

Analysis of Rain Water, Leeds and Garforth.

Total for Year, November 1907 *to October* 1908, *expressed in Pounds per Acre.*

—	Collecting Station		Suspended Matter	Tarry (Ether-soluble) Matter	Mineral Matter	Free Acidity as H_2SO_4	SO_3 (Total, Free and Combined)	SO_2	Chlorine	Nitrogen as NH_3	Nitrogen as N_2O_5	Nitrogen as Albuminoid Ammonia	Total Nitrogen
1	Leeds Forge	Industrial	1,886	110	1,113	35	123	34	164	13·0	0·0	4·7	17·7
2	Hunslet	Industrial	1,565	69	655	90	185	24	198	15·5	0·0	2·9	18·4
3	Beeston Hill	Industrial	1,163	149	709	30	269	54	101	14·4	0·5	3·5	18·4
4	Philosophical Hall	Industrial	849	78	423	45	149	38	75	14·4	0·3	2·2	16·9
5	Headingley	Residential	659	43	199	11	118	32	41	11·1	1·1	0·8	13·0
6	Armley	Residential	593	34	216	29	110	37	108	9·9	1·0	3·2	14·1
7	Observatory	Residential	399	32	146	26	85	39	51	8·4	0·8	1·6	10·8
8	Kirkstall	Residential	352	28	141	8	77	56	57	7·7	0·2	2·3	10·2
9	Weetwood Lane	Residential	147	26	54	11	82	13	34	8·3	1·1	2·1	11·5
10	Roundhay	Residential	90	14	49	0	53	16	38	5·8	0·7	1·3	7·8
11	Garforth	Country	—	—	—	28	65	21	22	5·0	3·2	1·1	9·3
12	Garforth (average three years)	Country	—	—	—	20	70	21	21	6·4	1·9	1·4	9·7

Further investigations have been made as to the influence of the suspended impurities upon the amount and intensity of the light penetrating the atmosphere at the different stations.

A three years' experiment is recorded showing the influence of acid waters (including Leeds and Garforth rain) upon the growth of grass. The grasses have been grown in boxes, each one foot square, and subjected to precisely similar conditions with the exception of the acidity of the water supplied. Observations have been made of the effect upon the yield and composition of the

grasses and upon the micro-organic flora of the soil. The results direct attention especially to the following points :—

(*a*) *The high amounts of suspended matters in town air.*—This is not only directly injurious to vegetation in blocking up a large proportion of the stomata of leaves, but exercises also a considerable influence upon the amount and intensity of the solar radiation placed at the service of town vegetation. The injury due to the former cause is greatly aggravated by the sticky nature of much of the suspended matter (tar, &c.), and is most markedly seen in the case of evergreen plants, conifers being the most susceptible. The characteristic sunk stomata of these latter plants, whilst serving admirably for the restriction of transpiration, act as traps for the solid matters suspended in the atmosphere. Some leaves have been found to have as many as 80 per cent. of their stomata so blocked. The well-known detrimental effect of the gaseous products of combustion of coal upon the growth of these plants is thereby intensified. Conifers cannot be grown with even moderate success in Leeds, except upon the northernmost verge where the atmospheric impurities reach their minimum.

(*b*) *The relatively high acidity of town rain, especially in the industrial districts.*—The investigations show that the rain falling in practically every part of the city is distinctly acid. The injurious effect of this acid upon vegetation, as illustrated by the growth of grass, is brought out clearly by the experiments. The injury is probably partly direct, but it is shown to be due in part to the effect of the acid upon the micro-organic flora of the soil. The reduced yield, lower protein-content, and increased fibre-content of the grass grown under acid conditions is a matter of serious import for the farmers in semi-urban districts.

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2. *Some Troublesome Diseases of the Potato Tuber.*
By A. S. Horne, *B.Sc., F.G.S.*

Some years ago a disease of the potato tuber, due neither to *Phytophthora infestans* nor *Fusarium solani*, was described by Frank under the name Buntwerden or Eisenfleckigkeit, which possessed only internal symptoms, taking the form of brownish blotches or streaks in the flesh. Corresponding to Buntwerden are the types known in Britain as internal disease and sprain (streak-disease), the flesh being marked with blotches and streaks respectively. The markings in both cases are constant for large samples of potatoes of a known variety and have received separate consideration, since it has not yet been shown that they are due to the same cause. No hyphal organism is present in typically affected tubers—if pathogenic organisms are responsible for the disease, they are probably bacteria. Diseased seed-tubers are liable to propagate the disease.

Internal disease is often associated with *Phytophthora infestans* (from the soil). The tubers in a given sample affected with blotches only show no external marks, but others of the same sample with the complication can be detected at a glance. When the tuber is cut open there is generally a peripheral zone of the fungus, whilst the central portion is blotched.

In spite of Frank's description of two types of an attack of *Phytophthora*, that type which consists of an attack upon the tuber from the soil, which, in the north of England and in Scotland often takes the form of a joint incursion of *Phytophthora* and bacteria, is considerably neglected in some parts of the country, although responsible for extensive damage to crops. Spraying, although perhaps beneficial to the plant, is not a proper remedy, since the disease is as bad under healthy as under unhealthy tops. Affected tubers when examined immediately after removal from the soil show a peripheral zone of disease, but the stalk end is frequently quite clean. In microscope sections the fungus and motile bacteria can be seen in the intercellular spaces and the points of entry of the organisms concerned can be traced.

Another form of disease which appears towards the middle of the storage period is locally known as bruise. No pathogenic organisms have yet been recognised, but, in any case, the disease leans strongly towards the physiological side, since it seems to be eliminated by a suitable change of soil and climate.

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3. *A Preliminary Note on the Fatty Substances in Oat Kernel.* *By* Professor R. A. Berry, *Ph.D.*

It has been shown by Maxwell, Schulze, Hoppe-Seyler, and others that the ether extract of plants may contain, in addition to the oil, other bodies such as waxes, hydrocarbons, colouring bodies, lecithin, cholesterins, &c., in varying amounts, and that prolonged digestion with the solvent is necessary for the extraction of the oil from seeds. Dry oat kernel was subjected to repeated five-hour extractions with different solvents, 5 grs. in duplicate or quadruplicate being taken in each case, with the result that ether, chloroform, light B.P. petroleum ether, and carbon tetrachloride extracted over 95 per cent., absolute alcohol 92·5 per cent., benzene 89·24 per cent., and acetone 88·9 per cent. of the total extract in the first of three five-hour extractions. The ether extractions were repeated six times, and the last extraction still gave an increase of 1·7 per cent. The oil from the chloroform and alcohol extract was turbid; in the rest it was clear. Invariably the second and third extractions were partly solid. In the case of chloroform it was a clear crystalline solid. The residual meal after the thirty-hour ether extraction was extracted for a further five hours with absolute alcohol, and yielded 0·083 gr. extract; and the residual meal from the fifteen-hour alcohol extract yielded, with a further five hours' extractions with ether, 0·004 gr. extract. The former was composed mostly of lecithin. Taking the total ether extract of three five-hour extractions as 100, the ratio for the other solvents obtained in the same way are: Petroleum ether 97·07, carbon tetrachloride 104·24, chloroform 109·78, acetone 112·71, benzene 113·15, absolute alcohol 127·93.

Pure dry ether, compared with ordinary ether, with a fifteen-hour extraction yielded the following results calculated as percentages of the dry meal:—

	Dry Ether	Ordinary Ether
Dry meal	9·25	9·43
Air-dry meal	9·40	9·72

Dry ether and dry meal yield the purer oil.

Oat oil from the dry ether extract gives a saponification equivalent of 265, potash absorption 21·2 per cent., iodine absorption 99·9 per cent.; and it contains 4 per cent. of free fatty acids calculated as oleic acid. With nitrous acid a solid claiden was formed.

The greater part of the lead salts of the fatty acids were soluble in ether, and yielded fatty acids liquid at the ordinary temperature, with a mean combining weight of 254 and iodine absorption of 106. The fatty acids from the insoluble lead salts were solid. Small amounts of unsaponifiable matter were found in all the extracts.

FRIDAY, SEPTEMBER 2.

The following Papers were read:—

1. *Sugar-beet Growing and Beet-sugar Manufacture in England.* *By* Sigmund Stein.

Sugar-beet growing in the United Kingdom dates back to 1835, when sugar-beet was grown experimentally in Surrey. In 1853 a small beet-sugar factory was erected at Mount Mellick, Queen's County, Ireland. Later, experiments were carried out in different parts of the country, and in 1867 Mr. Campbell, of Buscot, near Faringdon, grew sugar beetroots on a more extensive scale. About 1870 a beet-sugar factory was started at Lavenham, but it failed. Since then many experiments have been carried out by various agriculturists and scientists.

During the last twenty years the author has carried out about four thousand sugar-beet growing experiments in practically every county in England, Scotland, and Ireland. Thirty-six different seeds were used, including German, French, Austrian, Russian, Dutch, and English. The average results show a yield of sugar-beet with leaves of 39 tons 5 cwt. per acre. The average yield of roots

without leaves was 17 tons 16 cwt. per acre, but in many cases 28, 30, and 35 tons of roots per acre were obtained. The author's experiments on the Liverpool Corporation Sewage Farms in 1900 produced a yield of 43 tons of sugar-beet per acre. The average of the sugar contents was 17·65 per cent. in the roots and 19·15 per cent. in the juice, but several samples contained 21 per cent. of sugar.

Our climate is most suitable for root-growing, specially for sugar-beet. The ridiculous 'sun fable' was disputed many times by the author and others. In years when there was a failure of the beet crop on the Continent he grew excellent roots in England. His balance-sheet published some years ago shows that it costs 9*l*. 15*s*. to grow an acre of sugar-beet. If the farmer receives 1*l*. per ton for his sugar-beet he will have a profit of 6*l*. 10*s*. per acre.

The demand for mangolds is limited, and the price varies. Sugar-beet, however, is contracted for at a fixed price for five to ten years. Farmers will have a sure profit for years to come.

Sugar bounties were abolished by the Brussels Convention until 1913, and if the present sugar policy be preserved by England the Convention will become a permanent institution.

The consumption of sugar is increasing from year to year, and is caused (*a*) by the natural increase of the world's population; (*b*) by the increased consumption of sugar owing to the abolition of the bounties; (*c*) by the increase of education and intelligence. The consumption of sugar in England is 88 lb. per head per annum. Confectionery, marmalade, preserve, and mineral-water industries are interested in it. If England does not begin to produce sugar, there will soon be a sugar famine. We require 500 factories, each costing 80,000*l*.; so that 40,000,000*l*. will be safely invested at home. We shall keep the 20,000,000*l*. at home which we have sent out year by year abroad. In the factories 160,000 hands will be employed and hundreds of thousands indirectly.

Beet pulp is very valuable feeding material; 25,000,000 tons of it are used annually on the Continent for cattle-feeding. Saturation lime is a valuable manure, supplied free or cheaply to the farmers.

We have now experimented for seventy-five years; it is high time to utilise our experience and erect factories in every county. The author has indicated suitable sites in different localities, and preparations are already being made for the erection of beet-sugar factories. The beet-sugar industry will be a great and profitable industry, and will prove of immense benefit not only to British agriculture but to the whole population and the entire country.

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2. *The Financial Aspect of the proposed Sugar-Beet Industry.* *By* G. L. Courthope, *M.P.*

This paper dealt with the question from the three aspects of the nation, the farmer, and the sugar manufacturer. Attention was directed to the fact that the imports of beet sugar have increased during the last thirty-five years from a negligible quantity to some 30,000,000 cwt. annually. There is no reason why this vast production should not have been built up at home. Successive Governments have failed to foster the industry and have done nothing in connection with bounty-fed competition from abroad. With the acceptance of the Brussels Convention the situation has completely changed. The doubt still remains as to whether any Excise duty will be placed upon the product of home factories, but various considerations render it unlikely that any such duty will be imposed for some years to come. The opinion was expressed that there would be little or no loss of revenue to the Treasury, since with existing taxation the contribution to the Exchequer would be fully equal to the present import duty of 1*s*. 10*d*. per cwt. so long as the wholesale price of sugar did not fall below 14*s*. 8*d*. per cwt., as against current quotations varying from 20*s*. 10½*d*. to 22*s*.

The author is of opinion that on any land which will grow a good crop of mangold, and is situated within reasonable distance from a factory, the farmer should be able to make an average annual profit of about 6*l*. to 6*l*. 10*s*. per acre, in addition to receiving the 'saturation lime' free, having an additional local supply of cheap cattle-food, and also the expectation of a bonus from the factory in years of success. He would gain the two eminently desirable advantages of a

certain market and prompt payment for his crop. The 'saturation lime' given gratis to the farmer contains all the chief manurial ingredients and is of distinct manurial value. The dried slices or pulp (the so-called 'Protos') are said to possess a greater feeding-value than either hay, bran, barley, or the commonly used meals and cakes.

From an examination of Continental experiences it is considered that a factory dealing with the produce of about 2,500 acres is the most profitable. Such a factory would deal with, say, 36,000 to 50,000 tons of roots during a campaign of not more than a hundred working days. Buildings and plant would cost 70,000*l.* to 90,000*l.*, according to the methods and machinery employed. In addition, the site has to be purchased, sidings constructed, and roads made. The cost of the first depends upon local circumstances; the second, assuming the site to be close to a railway, would probably cost from 3,000*l.* to 4,000*l.*, and the third from 3*l.* to 4*l.* per yard run. The total cost of erecting, equipping, and starting such a factory is computed at 120,000*l.* Assuming that the farmer is paid 18*s.* per ton for his beet, and that the factory effects a sale of 5,000 tons of granulated sugar at 14*l.* per ton, 5,000 tons of dried slices at 5*l.* per ton, and 375 tons of molasses at 3*l.* 15*s.* per ton, an estimated profit is arrived at of roughly 31,000*l.*, or 25 per cent. upon the capital invested.

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3. *The Fixation of Nitrogen by Free Living Soil Bacteria.* *By* Professor W. B. Bottomley, *M.A.*

Since the discovery of the Azotobacter group of nitrogen-fixing organisms by Beijerinck in 1901 numerous attempts have been made, but with little success, to utilise these organisms for increasing the store of soil nitrogen. Gerlach and Vogel (1902) and Freudenreich (1903) obtained negative results in soil experiments. Lipman (1904), experimenting with *Az. Beijerincki* and *Az. Vinelandii*, found that out of ten experiments there was a *loss* of nitrogen in every case but one, and this showed a gain of only 4 mgs.

Certain results from inoculation experiments on clover with oats in 1907, and the discovery that species of Azotobacter and Pseudomonas are always found in association in the algal zone of the root-tubercles of Cycas, suggested that a mixed culture of these organisms might be effective in fixing nitrogen in the soil.

Pure cultures of the organisms obtained from Cycas root-tubercles incubated for fifteen days at 24° C. gave the following :—

	Mgs. N. per unit Carbohydrate per 100 c.c.
Control	0·48
Azotobacter	0·56
Pseudomonas	0·91
Azotobacter+Pseudomonas	1·24

Hence Azotobacter and Pseudomonas fix more nitrogen per unit of carbohydrate when grown together than when grown separately. Further investigation showed that this increased fixation applied also to Azotobacter and Pseudomonas from ordinary soil and leguminous nodules respectively. Pure cultures grown in a solution consisting of mannite, 0·5 grm.; maltose, 0·5 grm.; potassium phosphate, 0.1 grm.; magnesium sulphate, 0.02 grm. per 100 c.c. of water, at 24° C. for ten days, gave the following averages :—

	Mgs. N. per 100 c.c.
Control	0·53
Azotobacter	2·19
Pseudomonas	2·30
Azotobacter+Pseudomonas	4·51

Owing to the different cultural conditions prevailing in soil and culture solutions an attempt was made to acclimatise the pure cultures to ordinary soil conditions. About fourteen pounds of autoclaved garden soil was well moistened with the mixed culture and incubated for twenty-one days at 24° C. A culture

solution was then obtained by mixing 5 grm. of this inoculated soil in 100 c.c. of water with 1 grm. of sugar and incubating for twenty-four hours only; 50 c.c. of this solution were then applied to pots containing 5 ounces of soil each, and incubated at 24° C. for ten days. The nitrogen determinations yielded :—

	Mgs. N. per 100 grm.
Soil+50 c.c. distilled water	324
Soil+50 c.c. autoclaved culture	330
Soil+50 c.c. living culture	359

An increase of 35 mgs. nitrogen per 100 grm. of soil, which represents an increase of about 350 lb. of nitrogen per acre, taking an acre of soil 4 inches deep as weighing 1,000,000 lb.

To further test the effect of the mixed culture (both pure culture and soil culture) under ordinary conditions on different soils a number of shallow plant-dishes, each containing 3 lb. of soil and inoculated with 300 c.c. of the culture, were kept in one of the greenhouses at the Chelsea Physic Gardens for fourteen days. Analyses of these gave the following averages :—

	Soil A	Soil B	Soil C	Soil D
	Mgs. N. per 100 grm. Soil			
Control	371	375	312	402
Pure culture	403	396	336	421
Soil culture	406	395	333	424
Increase.				
Pure culture	32	21	24	19
Soil culture	35	20	21	22

Experiments in progress indicate that this fixed nitrogen is readily assimilated by plants, and crops are benefited by an application of the mixed culture.

4. *Notes on the Nature of Nitrogen Fixation in the Root Nodules of Leguminous Plants.* *By* JOHN GOLDING, *F.I.C.*

Nearly a quarter of a century has elapsed since Hellriegel and Wilfarth showed that leguminous plants are able to assimilate the free nitrogen of the atmosphere when nodules are developed on their roots; but the problem of what takes place in the root nodule is still unsolved.

Numerous researches have led to the following conclusions :—

(1) That the plant is able to get all its nitrogen from the air of the soil, and that the quantity fixed is very large.

(2) That the nodule is the seat of the process.

(3) That fixation is accompanied with a change in the form of the organism, which invades the root hair as an infection thread, passes through a rod-shaped stage, and finally assumes the (Y) bacteroid form.

(4) That practically each plant has its own nodule organism, and though the differences seldom amount to a difference of species, it takes a considerable time for the nodule organism of one plant to become adapted to another plant, and when so adapted it is not capable of infecting the plant from which it was first taken.

(5) That this adaptation to a particular kind of plant is retained by the organism in the soil for a considerable period, during which assimilation, if it takes place at all, is much less than when the organism is in the nodule.

The conditions which obtain in the nodule are as follows :—

The acidity of the cell sap must be contended with. Nitrogenous products of growth must be removed at an early stage of development of the plant. The organism must be fed with some carbohydrate, to give it the necessary energy to fix the nitrogen. Some limiting factor must restrict the number and size of the nodules. Chemical differences must exist between the roots of nearly related plants to which the organisms must be very sensitive. The atmospheric conditions obtaining in the nodule may also differ from those in artificial cultures.

The study of the behaviour of these organisms under controlled conditions of artificial culture, approximating as far as possible to the natural conditions, indicates a solution of the problem in the near future.

In some work on the subject quantitative determinations of the nitrogen fixed have been the measure of advance, while in others the formation of bacteroids, or of slime, or even the power of infecting plants, has been taken to indicate an approach to natural conditions.

A new method described and demonstrated for the first time indicates that it is the reaction of the medium which plays an important *rôle* in nitrogen-fixation. The cultures also disclose previously unobserved properties of the nodule organism.

Previous work is summarised, indicating that it is not only the acidity of the root sap, but also the removal of the products of growth, the supply of carbohydrate, and the slime production which must be regulated before artificial cultures of the organism can be expected to fix nitrogen to an extent comparable with that which takes place in the nodule. The ready adaptation of the organism to its environment must also be borne in mind.

MONDAY, SEPTEMBER 5.

Joint Meeting with Section D.

The following Paper was read :—

The Part played by Micro-organisms other than Bacteria in determining Soil Fertility. By E. J. RUSSELL, *D.Sc., and* H. B. HUTCHINSON, *Ph.D.*

Partial sterilisation of soil by heat or treatment with volatile antiseptics such as toluene leads to a notable increase in productiveness. The authors find that shortly after the treatment has ceased there is a great increase in the rate at which plant food is formed by bacteria and in the rate of multiplication of the bacteria. This increased activity is not brought about by any heightened vigour in the bacterial stock; on the contrary, it is shown that these organisms are actually weakened by the treatment. It follows, then, that the environment has been improved.

When some of the original untreated soil or an aqueous extract of the soil is added to the partially sterilised soil there is at first a still greater increase in the bacterial activity. This has been traced to the addition of the more vigorous organisms of the untreated soil. Later on there is evidence that a detrimental effect is produced where soil was added, but not from the extract. It appears, then, that the untreated soil contained some injurious factor not washed out by water, which only slowly makes itself felt when introduced into a clean soil. This factor is put out of action by any poisonous organic vapour by heating to 52° and similar means.

It is difficult to account for the experimental results in any other way except by supposing that soil contains organisms capable of checking bacterial development. Such organisms must be larger than bacteria and not readily detached from the soil since they do not appear, or not to any extent, in an aqueous extract. Search for large organisms has revealed the presence in every soil so far examined of amœbæ or amœboid organisms, of colopoda and other protozoa. It is shown that the mixed culture growing in hay infusion is capable of destroying bacteria. It has not yet, however, been possible to ascertain definitely whether these protozoa are active in the soil, although the conditions obtaining—an atmosphere saturated with water vapour and a film of water round the particles of soil—would seem to us favourable to their development.

The following Paper was read in Sub-Section B (Agriculture):—

'Points' in Farm Livestock and their Value to the Scientific Breeder.

By K. J. J. Mackenzie, *M.A.*, *A.S.I.*

Since Bakewell (1725-95), a Leicestershire yeoman living at Dishley, improved the 'Longhorn' breed of cattle and the 'Leicester' breed of sheep through selection and 'in and in breeding,' the advance in the value of British farm stock has been phenomenal. Almost simultaneously with Bakewell's improvements in breeding, the work of Jethro Tull and of Lord Charles Townshend led to a new husbandry whereby it was possible to feed cattle and sheep liberally all through the year. It is possible that this latter fact had a great part in the improvement of livestock, and that some of the credit so often given solely to the breeder may be really due to changed environment or conditions of nutrition.

Great economic results have accrued from the improvement in British breeds of farm livestock begun by Bakewell, but carried on by others and applied by them to other varieties of cattle, sheep, horses, and swine. In fact, during the last hundred years practically all the new countries of the world, as well as many of the older ones nearer us, have drawn on these islands for their pedigree livestock. This fact has played no small part in helping the British agriculturist to tide over the great depression of the last quarter of the nineteenth century. It is remarkable that, notwithstanding a vast outlay in purchasing foundation stock and in getting men to manage it, a foreign demand for animals of the best type for breeding purposes still exists.

Great as have been the results obtained in the past by British breeders of livestock, results which are possibly, as we have seen, partly due to improvements in general agriculture, there is hope of still further advance owing to the work of those investigators who have followed up the discoveries of Mendel and others who have brought the mysteries of breeding within the scope of pure science. It seems likely that a closer study of those indications, spoken of as 'points,' which Bakewell and his immediate, as well as his present-day, followers have used in their practical work, may be of value to the purely academic worker who would bring the result of scientific research to bear upon the question of economic stock-breeding.

The investigation of such 'points' demands much research, for at present they are very vaguely defined, and breeders would seem, to a certain extent, to work by intuition rather than by definite knowledge. It would seem necessary, before the practical breeder can be in a position to get help from men of science, to examine these 'points' with care, so that:—

(*a*) All the factors which are necessary for the development of any one 'point' may be ascertained.

(*b*) We may know whether the 'points,' necessary for the development of any one particular form of usefulness, may be correlated with 'points' denoting utility of another sort.

(*c*) We can ascertain whether 'points' which empirical methods have fixed upon as indications of certain useful faculties are, in fact, necessary to the development of those faculties, or whether they are simply due to fictitious considerations sometimes called 'fancy.'

The value of certain 'points' supposed to indicate deep-milking properties was investigated by a study of Lord Rayleigh's herds, to which he kindly allowed the writer access. Forty of the best and forty of the worst milkers were measured, and the results worked out by correlation methods. Although the investigation is not complete, it does not appear so far that the 'points' are closely correlated with milk production.

If it be found possible by counting or weighing, or in any other accurate manner, to bring the 'points' sought for within the range of ascertained fact, it will greatly assist the men of science in suggesting improved systems of breeding to the stock-rearer.

There are many other characteristics, such as 'touch,' 'constitution,' and 'kindliness,' upon which practical men rely, but which cannot be said to be well defined. Such characteristics are, however, held to be of the utmost importance, and it would seem well to investigate them. In fact, to ignore them may be to deprive of very useful help those who wish to emulate in the future the great improvement in the past.

Joint Meeting with Section C.

The following Papers were read :—

1. *Soil Surveys for Agricultural Purposes.* *By* A. D. HALL, *F.R.S., and* E. J. RUSSELL, *D.Sc.*

The object of a soil survey is to give an account of the soils of an area in their relation to the local agriculture. The methods adopted must be such that it is possible (1) to classify together soils of the same formation which have similar agricultural properties, and differentiate between others with dissimilar properties; (2) to bring out clearly and unmistakably any connection that may exist between type of soil and special crops or special agricultural methods; (3) to afford guidance as to crops that may succeed, or are not likely to do so; (4) to throw light on the manurial requirements of the soils.

The geological formation affords the best basis on which to carry out a soil survey. Where fairly constant physical and other conditions have obtained a fairly constant type of soil may be expected. Thus, in their survey of Kent, Sussex, and Surrey, the authors found that soils arising from the Bagshot and Folkestone beds, although both light sands, possessed definite characteristics whereby it was generally possible to distinguish them. In other cases gradual changes can be traced in passing along the formation : thus, the Hythe beds in the east contain a distinctly large proportion of the finest particles of soil, which becomes less and less in moving westwards.

Considerable difficulty comes in, however, where the formation is obscured by drift.

Of the various determinations made in the course of the analysis, the most important is the mechanical analysis whereby the particles are graded according to their sizes. For agricultural purposes the size of the soil particles is more significant than their actual composition. The finer particles of soil regulate the water-supply available for the plant, and profoundly influence the tillage operations; unless a sufficient proportion is present the soil cannot be cultivated, but is left as waste, agriculturally speaking, though it may be valuable for building purposes. On the other hand, too great a proportion is detrimental, because it increases the difficulty of tillage. The coarser particles determine the openness and 'lightness' of the soil. A number of crops have very special soil requirements, and are only found in any quantity on a particular type of soil. It is possible to define these types over a given area by means of mechanical analysis.

Account must always be taken of the other factors determining the water-supply, such as rainfall, topographical position, nature of the subsoil, &c. Temperature is equally important, and the altitude and exposure has also to be considered.

Of the chemical determinations the total carbonate is, perhaps, the most important. Calcium carbonate is the commonest of these compounds, and it acts in two ways : it modifies the properties of the finer particles, making them more like coarser particles, and it prevents the soil from becoming acid. It is impossible to lay down any limits within which the carbonates must fall, an amount sufficient on a light sandy soil being wholly insufficient on a clay. The amount should increase *pari passu* with the amount of fine particles.

The amount and nature of the organic matter is important, and it is necessary to know whether free acid is present or not. Like calcium carbonate, humus modifies the properties of the finest particles.

The inter-relationships between size of particles, water-supply, and amounts of calcium carbonate and organic matter cannot at present be reduced to any mathematical expression, and, owing to their complexity, certain field observations are necessary. But it is usually possible to interpret the results with sufficient precision for ordinary purposes.

Of the bases, the amounts of alumina and of potash vary with the clay, but iron oxides do not necessarily. The proportion of ferrous to ferric iron is important as an indication of the amount of aëration in the soil.

2. *The Drift Soils of Norfolk.* *By* L. F. Newman.

The central and eastern parts of Norfolk are almost completely covered with drift, classified for mapping into three divisions by the Geological Survey Department :—

1. Boulder clay.
2. Sands and gravel.
3. Loam and brick-earth.

The soils of each, especially the boulder clay, vary very much in character and are extremely complicated, and small local differences occur even in soils resulting from the same type of drift. The sand and gravel soils are very apt to be cemented together by iron, forming a solid sheet of rock out of reach of the plough. This holds the water up, and peaty patches may occur completely altering the agricultural character of the land. In soil derived from the solid chalk the lime is often completely dissolved, leaving the soil actually deficient in lime.

Woodward, in his memoir of the north Norfolk districts, says : 'Much of the soil of the central and western parts is of a changeable and mixed character, from the fact that the gravel and sand which originally extended over a very considerable part of it have left indication of their former presence in the soil.'

And again : 'The glacial drift of this area comprises almost every kind of sedimentary and detrital formation, from chalk, mud, marl, clay, and loam, to sand, gravel, and boulder gravel. The map distinguishes as far as possible the marly and loamy beds from the sand and gravel; but at best this is a lithological division, and it is difficult to be consistently accurate even in this respect, for the beds give evidence of great disturbance and contortion, and also of abrupt change in lithological character. . . . It is not possible to separate the gravel from the sand on the map, and even the boundary between the brick-earth and the marl or boulder clay is only approximate.'

The chalk outcrops along the north coast, and the resulting soils, which on the hilly parts are only about four inches deep, grow the best barley in England. In the valleys, however, the soil is deeper, probably due to a natural warping. A correlation of these soils has yet to be made out.

Nearly all the surface drift is deficient in lime, and wherever the marl or chalky boulder clay is near the surface it has been dug into for the purpose of carting it on to the land. Practically the whole country has for many years been under the Norfolk or four-course system of farming, and this rather obscures the natural capabilities of the land, hence the crop returns are less valuable as an indication of soil character and fertility than is usually the case.

In making a soil survey the first step is to make a preliminary tour, selecting samples from various parts, and afterwards going again over the land and taking a further series to fill in details and complete the chain of results.

Such a preliminary survey of the drift showed that the loams and brick-earths had a strong likeness one to another. The percentages of the finer particles decreased in each sample from east to west, which decrease was reflected in the gradual lowering of the rentals of the farms lying along the lines of sampling.

The sand and gravel also fell into lines of :—

1. High and low stone percentages.
2. High and low percentages of coarse sand, the great quantity of which makes all the soils very open and inclined to 'burn.'

Much of the gravel was under conifers or was common or waste land.

The boulder clays showed very great variations, small areas showing similarity of composition but differing markedly from other areas a mile or so away. It would appear that a complete soil-map of the boulder clays would emphasise and explain some of the differences alluded to in the Memoirs of the Geological Survey.

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3. *The Scouring or 'Teart' Lands of Somerset.* *By* C. T. Gimingham, *F.I.C.*

In certain districts of mid-Somerset the herbage of much of the pasture land has the property of causing cattle feeding there to scour very seriously indeed

at certain times of the year. Such pastures are known locally as 'teart' or 'tart' land, and their presence considerably lowers the value of farms in the district. The area of land involved may be very roughly put down as fifteen thousand acres, and since the whole of this part of Somerset is devoted to dairy farming and is nearly all pasture land, it is a problem worthy of attention, to investigate the cause, and, if possible, to find some remedy for this condition.

The extent to which the scouring properties of the herbage are developed varies greatly in different places. Scouring and sound pastures are often intermixed in a very intricate manner. It is therefore not possible to make any reliable estimate of the actual financial loss which may be put down to this difficulty.

All kinds of cattle are affected, cows in milk being the worst sufferers. Lambs also scour badly. Sheep and horses, however, are exempt.

Scouring is usually most prevalent in the autumn—when cattle are fed on the aftermath—and as a rule the more abundant the growth the more serious the trouble becomes, varying with the season. Also individual animals vary in the degree to which they may be affected.

'Teart' land in Somerset is entirely confined to one geological formation, the Lower Lias. The typical surface soil on the Lower Lias here is an extremely stiff unyielding clay, with the blue or yellow lias clay subsoil not far below. Where this formation is obscured by deposits of alluvium or drift, giving rise to a soil of an entirely different type, the pastures are all quite sound. The physical natures of the soils of adjoining sound and 'teart' fields have been compared, and the results tend to show that this is a factor of much importance.

So far it has not been found that the chemical composition of the herbage is peculiar in any way.

Scouring on 'teart' land has been attributed to a variety of causes, among them the presence of some particular plant in the herbage, or a bad water-supply. Neither of these explanations, however, can be substantiated.

The usual result of the application of manures to 'teart' pastures is to make matters worse with increased growth, and where large numbers of sheep are fed in these fields the same result is noticed. On the other hand, the first two or three sharp frosts remove all tendency to cause scouring from the autumn herbage.

It is possible to ascribe the peculiarities of 'teart' land either (1) to the production of abnormal compounds in the herbage affecting the animal, directly or indirectly, by causing unusual fermentations to be set up in the intestines; or (2) to a specific organism picked up from the grass or soil. These two hypotheses were compared and discussed.

TUESDAY, SEPTEMBER 6.

The following Papers were read :—

1. *The Cost of a Day's Horse Labour. By* A. D. Hall, *M.A.*, *F.R.S.*

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2. *Costs in the Danish System of Farming. By* Christopher Turnor.

Joint Discussion with Section F on the Magnitude of Error in Agriculture Experiments,

(i) *Scientific Method in Experiment. By* Professor H. E. Armstrong, *F.R.S.*

(ii) *The Interpretation of Experimental Results. By* Professor T. B. Wood, *M.A.*, *and* F. J. M. Stratton, *M.A.*

(iii) *The Accuracy of Feeding Experiments.* *By* Professor T. B. Wood, *M.A.*, *and* A. B. Bruce.

In the published results of feeding experiments on the comparative merits of different diets for cattle and sheep there is a tendency to base conclusions on the average result of a single experiment with a small number of animals without regard to the degree of variability between different individuals.

If no regard be paid to individual variability it is desirable either to experiment with a larger number of animals in each lot than has hitherto been customary, or to repeat the experiment several times.

In the case of cattle a very usual number is six, and eight is practically the maximum. A consideration of the published figures for individual animals justifies the assertion that these numbers are so small that the average has very little weight. In fact, the individual variations are generally so large that it is doubtful whether trustworthy results can be obtained with fewer than twenty animals.

A measure of the reliability of the mean result of an experiment can be obtained by calculating the probable error from the individual results. This is a measure of the variability, inasmuch as the figure gives the limits within which it is an even chance that the mean will lie. From a consideration of the figures obtained in a feeding experiment carried out under the supervision of the Cambridge School it is shown how fallacious any conclusions based on the mean of a small number of animals may be.

From a general review of feeding experiments it is suggested that an investigation of the causes (and perhaps the heredity) of individual variations in the capacity for fattening might be likely to lead to practical and useful results.

In arranging feeding experiments the common practice is to endeavour to select animals of equal weight and age and to make preliminary tests so as to pick out those of uniform fattening capacity. It is suggested that in order to ensure that the results of different experimenters should be comparable, either a uniform conventional method of selection should be adopted or selection should be avoided.

(iv) *The Sampling of Agricultural Products for Analysis.* *By* Professor T. B. Wood, *M.A.*, *and* A. B. Bruce.

The discrepancy between the analyses of agricultural products published by different chemists may be due to divergent methods of taking samples. It is accordingly desirable to give some consideration to the law of error in this connection.

To illustrate and explain the application of this law to sampling, certain figures obtained in an investigation into the composition of mangels are given. The most important formula in this connection is that which states that the accuracy of the analysis of a sample taken from a number of individuals is proportional to the square root of the number of individuals comprised in the sample. Thus, if a certain sample gives a probable error of r, and it is desired to obtain a figure for the mean with a probable error of $\frac{1}{2}r$, the sample should consist of four times as many individuals. The mangel results referred to above are used to prove the accuracy of this statement.

(v) *The Error of Experiment in Agricultural Field Trials.* *By* A. D. Hall, *F.R.S.*, *and* E. J. Russell, *D.Sc.*

Analysis of the causes of error show that they fall under several heads :—

(*a*) *Lack of uniformity in the soil.*—Even on a level field where no obvious variation occurs analysis shows that there are certain differences in different parts of the field. A sensitive and at the same time simple test is to ascertain the percentage of moisture in samples of soil collected to the same depth—six or nine inches—and as nearly as can be at the same time. The differences commonly amount to five (or in dry fields to ten) per cent. of the moisture present. Another factor greatly influenced by variations in the soil is the amount of nitrate present.

This affords an even more sensitive index of variation, since it depends on all the conditions favouring plant growth—moisture, temperature, air-supply, and foodstuffs, these being necessary for the production of nitrate—and also on the amount of water washing through the soil, nitrates not being retained like ammonium salts. Here, also, differences are found of the order of 5 or 10 per cent. of the amount present on fields that appear to be uniform. These differences may be accentuated where there is a dip in the field.

Variations in the field arise partly from natural and partly from artificial causes. So many agents come into play in soil formation that uniformity can hardly be expected. Further, the purely artificial operations, such as tilling, cropping, manuring, and folding, have a profound effect on the soil, persisting for some years. Frequently the treatment has not been uniform over the whole field. Drainage, whether artificial or natural, is rarely uniform: during a very wet winter it is not uncommon to see places in the field where wheat has been affected by differences arising either from lines of good drainage or patches of bad drainage. In other seasons the differences still exist, though not to so marked an extent.

(*b*) *Lack of uniformity in the conditions of growth.*—The conditions of the outside row of a plot differ from those obtaining inside the plot, and those on the outside of the field are much modified by the competition of hedges and trees. These difficulties can, however, be obviated. The unequal incidence of disease is sometimes very troublesome.

(*c*) *Effect of season.*—In manurial trials it is possible after a number of years to allow for the effect of season in a general way, especially as our knowledge of the properties of fertilisers increases. But in variety trials the problem is much more difficult, and cannot yet be said to be solved.

Total magnitude of the error of experiment.—An examination of the Rothamsted records shows that the error is 10 per cent. on plots where the past treatment has for many years been uniform, where all weighing, measuring, and other operations are performed with the utmost care, and where the general conditions are favourable for experimental work. Having regard to these considerations and the difficulties often encountered in field trials, the authors would not be prepared, as a general rule, to lay stress on differences of less than 15 per cent.

(vi) *The Application of the Theory of Errors to Investigations on Milk.* *By* S. H. Collins.

This paper was intended as a demonstration of the uses to which the theory of errors can be put. The theory of errors was applied to measurements of specific gravity, fat and total solids, with compound measures derived from them.

Lactometers were compared with a large plummet on a good balance giving the probable variation from the plummet of a single reading on the lactometer with the following results:—

1 small lactometer	1° = 1 mm.,	± 2	degrees lactometer
6 special lactometers	1° = 3 mm.,	± 0·55	„ „
8 „ „	1° = 1 cm.,	± 0·18	„ „
1 Westphall balance		± 0·47	„ „

Total Solids.—There are many sources of error in this determination. The rate of evaporation appears to be one of the large causes of error, but the rate of evaporation is itself dependent on many causes. Without attempting extreme variation of detail, but simply drying milk under such varying conditions as prevail in good laboratories, the probable variation of a single determination from the mean is found to be ± 0·068 per cent. Where work is carried out under rigidly uniform conditions the variation from the mean of one laboratory will be less, but for purposes of comparison between one laboratory and another the value given is not unreasonable.

Fat.—The probable variation of one determination by Gerber from the mean is ± 0·036 per cent. fat.

Propagation of Errors.—The error of solids not fat is found from the above data, and the formula $R^2 = r_1^2 + r_2^2 \ldots$ to be :—

By total solids . . .	± 0·077	per cent. solids not fat
By lactometer 1° = 1 mm.	± 0·5	„ „ „
By „ 1° = 1 cm.	± 0·045	„ „ „

The method was next applied to that part of the inaugural dissertation of J. H. Hinchcliff which attempts to measure the difference between calculated and found total solids. The error of such a difference is about ± 0.13, whilst nearly one-half of the observations fall within those limits. There is therefore no evidence that the use of the formula for calculating the total solids of the milk of one cow or one milking will not give close results. When the average of several milkings is taken the error is reduced, and the conclusions based on such averages are justified.

SECTION C.—GEOLOGY

PRESIDENT OF THE SECTION.—Professor A. P. COLEMAN, M.A., Ph.D., F.R.S.

THURSDAY, SEPTEMBER 1.

The President delivered the following Address :—

The History of the 'Canadian Shield.'

CAN there be any greater contrast than Pleistocene boulder clay resting on Archæan gneiss, the latest of rocks covering the earliest, with almost the whole known history of the world in the interval between? It is a fascinating occupation for a geological dreamer to sit on some hillside in Scotland or Finland or Northern Canada, where the schists and gneisses rise in rounded ridges or bosses through boulder clay, and ponder on all the strange happenings that separate the clay from the rock beneath.

The clay melting from its enclosed boulders under the frosts and rain seems the very emblem of the fleeting things of yesterday; while the Archæan gneiss and greenstones are the type of the solid, imperishable framework of the earth, on which all the later rocks rest.

The boulder clay recalls the white surface of a Continental ice-sheet with summer blizzards sweeping across it like those of the Antarctic tableland; while the gneiss beneath tells of a molten magma cooling during millions of years beneath miles of overlying rock.

It is the meeting-place of the geological extremes, and their contact marks the greatest of all discordances.

One thing the clay and the gneiss have in common—both were long neglected by geology; the Pleistocene beds because they were not rocks, but only 'drifts,' confused and troublesome things, hiding the real rocks, the orderly stratified formations; the 'basal complex' because its schists and gneisses were fossil-less, complex, and mysterious products of the dim beginnings of a world still 'without form and void.' The molten sphere, with its slowly consolidating crust, belonged rather to the astronomer than the geologist.

Geology has, of course, long lost that attitude, and now finds some of its most seductive problems in these once neglected extremes of the earth's history. Those who distrust the 'glacial nightmare' are now very few in number; but there are still revered veterans, like Professor Rosenbusch, who speak of the Archæan gneisses as parts of the earth's *Erstarrungskruste*, and who frame theories of the earth's cooling and wrinkling in its hot and furious youth.

Over more than half of Canada the field geologist is forced to occupy himself with both the Pleistocene and the Archæan, since the two are almost everywhere together, while the fossil-bearing beds of the vast intervening time are absent. The seemingly unnatural conjunction is not entirely without advantages, for the Pleistocene has furnished the clue to certain very puzzling problems of the Archæan, as will be shown later.

The geologists of the world have long known the broad outlines of the Canadian Archæan or Pre-Cambrian area through Suess's masterly portrayal of

the 'Canadian Shield,' and through Dana's account of the 'V Formation,' about which the North American Continent was built up.

It must be remembered, however, that, though most of the territory has been roughly traversed by Bell, Tyrrell, Low, and other explorers, only a few districts in the south have had their geology worked out in detail, because of their valuable deposits of silver, nickel, and iron ores. It is only in these districts and comparatively recently that the succession of Pre-Cambrian formations has been determined with certainty. In the wide spaces of the north only the most general relationships are known.

It is intended to bring together here our knowledge of the most ancient chapters in the history of North America as disclosed by recent field-work.

Physiographic Features.

In its physiography the Canadian Shield shows the features that might be expected from one of the oldest and most stable land areas of the world. It was reduced in very early times to a peneplain, but later was elevated, permitting the rivers to begin a process of dissection. This process had a recent interruption by the Pleistocene Ice Age, which blocked many of the valleys with moraines and gave rise to the most extensive tangle of lakes in the world. Physiographically as well as geologically, the region shows a dramatic mingling of extreme youth with extreme old age.

The best account of this rejuvenated peneplain has been given by Dr. A. W. G. Wilson,[1] who shows that the gradients are very gentle, and suggests that two or more facets can be distinguished as having slightly different inclinations and as having been carved at different times. Here it will be unnecessary to take the matter up except in a general way.

The peneplain has been unequally elevated, parts standing 3,000 or 4,000 feet above the sea, and other parts sinking beneath its surface. Only at two marginal points can the Archæan surface be said to rise as mountains—in the Adirondacks, projecting south-east into the State of New York; and in the Nachvak peninsula, just east of Ungava Bay.

To the south-west and south the shield sinks, almost inperceptibly in many places, beneath the older Palæozoic rocks, and the same is true around the central depression of Hudson Bay. Towards the south-east the shield breaks off suddenly along the great fault of the Lower St. Lawrence, and apparently the precipitous north-east shore of Labrador indicates faulting on even a larger scale. It has been suggested that Greenland, the Highlands of Scotland, Scandinavia, and Finland may have been parts of a single great shield, now separated through the settling down of the sea-bottoms.

In detail the region is full of variety of hill and valley, waterfall, river, and lake; but, on the whole, it is monotonous to the ordinary traveller from the constant repetition of similar forms, since there are no real mountain ranges and few outstanding 'monadnock' hills to break the sky-line. The sweep of horizon from every hilltop seems horizontal, the summits around seldom rising more than 200 or 300 feet above the valleys, and all reaching nearly the same elevation.

The geologist finds, however, that this impression of general flatness is deceptive. In reality the rock structures are usually more nearly vertical than horizontal, as in most Archæan regions. The schistose rocks, which form so much of the surface, commonly show dips of more than 60°, so that it is clearly a mountain region planed down to its foundations. The arrangement of valleys, ridges, and hills generally follows more or less closely these ancient rock forms.

Geological Structure.

Until recently most of the geological work done in this northern territory has been track surveys following Indian canoe routes. Here and there moraines or old lake deposits hide the rocks for a space, but usually the geology is admirably displayed as one's canoe threads the intricate waterways of sprawling lakes

[1] 'The Laurentian Peneplain': *Jour. Geol.*, vol. xl., No. 7, pp. 615–659.

spilling over from one irregular basin into another. On entering a new district there seems a hopeless confusion of pinkish gneiss and grey-green schist, but presently orderly forms take shape upon the map as the numberless bays and islands are explored, and the ground plan of vanished mountain ranges begins to show itself. Dr. Andrew C. Lawson, in his brilliant study of the Lake-of-the-Woods and Rainy Lake regions in 1884 to 1888, first brought out distinctly the relationships; and later work has added greatly to our knowledge of these ancient structures.

The typical arrangement is that of rounded or oval batholiths of gneiss, or of granite merging at the edges into gneiss, with schists dipping steeply away from them on all sides. Where the batholiths approach one another the green schists occupy narrow troughs between. As shown by Lawson, they are evidently the bottoms of synclines nipped in by the rising areas of granite and gneiss. Round these eruptive masses the schists have a strike parallel to the edge of the gneiss, so that they do not form ordinary synclines, but widen and narrow and swing in curves to adjust themselves to the varying relations of the batholiths. The meshes of green schist are often not complete, the curving ends feathering out to a point. In such places erosion has eaten the surface down below the bottom of the syncline.

The batholiths in Western Ontario are of all sizes, from a mile to 60 miles or more in diameter, and they are commonly somewhat elongated from west to east or from south-west to north-east. They do not always follow one another in orderly succession, but may lie scattered irregularly, almost like bubbles on foamy water. Yet on the large scale one can recognise a general trend in the direction of the longest axes of the batholiths, and the average strike of the schist in the various regions lies between 50° and 80° east of north, conforming to the same direction. This general east-north-east trend of the basement structures doubtless reveals the axial relations of the Archæan mountain ranges.

It is sometimes stated that the so-called V formation of North America was made up of two ranges converging toward the south, the easterly arm of the V parallel to the Appalachian mountains and the westerly one to the Rocky Mountains. The structural arrangement just outlined does not confirm this view, but suggests irregularly parallel chains, cutting the direction of the Rockies at about right-angles and that of the Appalachians at an acute angle.

Of what kind were the mountains erected on these bubble-like foundations of gneiss, set in meshes of schist? In many places they do not seem to have formed continuous ranges such as those of the Rockies, but rather groups of domes of various sizes. Some of them were comparatively low; others seem to have been lofty, though broad. Of the low ones the best known is that of the Grande Presqu' Isle in the Lake-of-the-Woods, an oval of gneiss 18 by 32 miles in dimensions. Here the up-swelling could not have been great, since the schists dip away from the gneiss at low angles all round, and patches of green schist, remnants of the roof, or perhaps of unusually large blocks stoped from above, are found here and there in the interior.

On the other hand, the Rainy Lake batholith, 30 by 50 miles in dimensions, must have risen as a lofty dome, since the surrounding schists dip away at high angles (60° to 90°). The arch of which they were the bases must have swung thousands of feet above the present surface of the batholith. Passing inwards from the Keewatin one finds at first immense slabs of the schist shifted a little and enclosed in gneiss, then bands of green material with softened edges, and finally darker cloudy streaks in the gneiss representing more perfectly digested bands. As Lawson has shown, the outer edge of the batholith is of greyish hornblende syenite gneiss or hornblende granite gneiss, while the interior is of ordinary mica granite gneiss. The outer part has absorbed a certain amount of basic Keewatin material.

One cannot doubt that this zone of green schist fragments, followed by greyish hornblende rock, originally extended over the dome as well as round its edges. In the middle there is now a width of 10 or 12 miles of the ordinary Laurentian gneiss. This implies, of course, that the upper part of the dome, afterwards removed, was several miles in thickness, and that the mountain mass rose correspondingly above the synclinal valleys. It must not be assumed that the dome had a regular surface, nor that it was unbroken. Such a batholith as that

of Rainy Lake was not made by a single sudden up-welling of granite, but by a long succession of slow inflows from various quarters. Meantime the rocks above must have been stretched and fractured during the long ages of elevation, and must have been exposed to the usual destructive forces, which may even have kept pace with the elevation during its late stages when differences of level became pronounced.

The coarse-textured granitoid gneiss making up the batholith must have cooled at great depths and exceedingly slowly.

The Raising of the Domes.

Some curious dynamical problems are involved in the raising of the domed mountains. It is conceivable that fluid lava could be forced by the unequal pressure of shifting mountain blocks through a suitable system of pipes into cisterns, so as to form laccolithic domes, but no such mechanism seems possible with batholiths. The granite of the batholiths was plastic rather than fluid, as shown by its having been dragged into the gneissoid structure. The areas affected covered sometimes 1,000 square miles. We know of no system of dykes to serve as pipes or passages, of no solid floor beneath, of no faulted blocks to provide the pressure. It is generally assumed that the protaxial granites and gneisses in great mountain ranges have risen because of the relief from pressure beneath anticlines due to lateral thrust. It is doubtful if these irregularly scattered ovals, sometimes 30 miles across, can be adjusted to any system of anticlines.

Some years ago I ventured another explanation. Granite is specifically lighter than most of the greenstones and schists of the Keewatin; and molten granite, even if not at a very high temperature, is lighter than the relatively cold rocks above it. If the rocks above were unequally thick, so that some areas were less burdened than others, it is conceivable that these differences in gravity might cause the granite to creep slowly up beneath the parts with the lightest loads, while the overlying rocks sagged into synclines in the heavily loaded parts.[1]

Whatever their cause, these oval batholiths enclosed by meshes of schist are the most constant feature of the Canadian Archæan, though in many places erosion has cut so deeply that the meshes have all but disappeared, leaving only straight or curving bands of hornblende schist enclosed in the Laurentian gneiss. Very similar batholithic relations of the Laurentian with the Grenville series of Eastern Ontario are described by Drs. Adams and Barlow, though the batholiths are generally much smaller. Batholithic mountains were typical of the Archæan in North America, and, at least in some cases, also of Archæan regions in other parts of the world.

Subdivisions of the Canadian Pre-Cambrian.

Until recently the rocks of the Canadian Shield were usually divided into three parts—the Laurentian, the Huronian, and the Animikie and Keweenawan —the last two being only doubtfully included in the pre-Cambrian. These three divisions are still the only ones shown on the latest general map prepared by the Geological Survey. Lawson's separation of the Keewatin as a lower group than the Huronian was generally recognised as valid, but in practice the subdivision of the two in mapping was difficult, and was only carried out in detailed surveys. His proof that the Laurentian was eruptive and later than the Keewatin was accepted.

As the classification adopted by the American geologists in the Lake Superior region differed from that used in Canada, a Correlation Committee was appointed five or six years ago to draft a compromise, which runs as follows :—

[1] Bull, *Geol. Soc. Am.*, vol. ix. pp. 223–238.

Keweenawan
Unconformity
Huronian { Upper (Animikie)
Unconformity
Middle
Unconformity
Lower }
Unconformity
Keewatin
Eruptive Contact
Laurentian

This compromise system is now generally in use in Canada, though if Canadian relationships alone were considered the Animikie would be separated from the Huronian and placed closer to the Keweenawan, and the Laurentian would be treated as consisting of eruptive rocks frequently later in age than the Lower Huronian.

The most natural classification for Canada would be as follows :—

Keweenawan
Unconformity
Animikie
Great Unconformity
Huronian { Upper
Lower }
Great Unconformity
Keewatin
Laurentian = Post-Keewatin or Post-Huronian granite and gneiss.

The laccolithic domes described on previous pages were formed partly in the interval between the Keewatin and the Lower Huronian, but mostly later than the Lower Huronian. Over much of the shield, however, our knowledge of the relations is not sufficient to separate the mountain structures of the two ages.

Let us now consider the history of the region during the successive periods suggested above.

Conditions during the Keewatin.

One naturally asks what the conditions were in Keewatin times before the earliest known laccolithic mountains were raised. The granitic texture of the eruptives implies very slow cooling under great pressure. The old interpretation of these rocks, following the usual conception of the nebular hypothesis, made them parts of the earth's original crust, which cooled under the tremendous weight of an atmosphere including everything volatile at red heat, an atmosphere 200 or more times heavier than at present. We know, however, that this cannot apply to the Laurentian gneisses of Canada, since they push up eruptively through great thicknesses of older rocks—the Keewatin in the north and west, and the Grenville series in the east, including large amounts of water-formed deposits. Though these older rocks are now found only on edge in synclines protected on each side by domes of gneiss, there can be no doubt that they once spread out wide and flat on the surface of the earth.

The eruptives of the Keewatin have received most attention, but sedimentary rocks occur in it at all levels and with thicknesses of hundreds or thousands of feet. They include Lawson's Couchiching, with its great areas of mica schist and gneiss formed from what were originally muddy and sandy sediments. In other places quartzites and arkoses, slates and phyllites, represent less metamorphosed clastic materials. The slate is often black with carbon. In the north-west there is little limestone or dolomite, but the Grenville and Hastings series of the east, which are probably in part of Keewatin age, contain thousands of feet of limestone. All the ordinary types of sedimentary rocks were being deposited on the Keewatin sea bottoms, and one type unlike modern sediments—the banded silica and magnetite or hematite of the 'iron formation.' The rock last mentioned belongs to the top of the Keewatin, and is very widespread. Its

crumpled jaspers have attracted much attention because of their association with iron ore, but in reality the other varieties of sedimentary rocks are present in far greater amount both as to thickness and extent.

In almost every part of the western region there are associated with the rudiments great sheets of basic lavas, agglomerates, and ash rocks, as well as smaller amounts of quartz porphyry, &c., showing that the Keewatin was one of the periods of great volcanic activity in the world's history. It is somewhat puzzling to find these predominantly basic volcanics in the Keewatin, while all the underlying eruptives of the Laurentian are decidedly acid, chiefly granite or syenite in composition.

The extensive sedimentary and eruptive rocks of this earliest formation imply that the ordinary geological processes were at work at the very beginning of known geological time, before the Archæan mountains came into existence. There must have been broad land areas where rocks like granite or gneiss weathered to mud and sand, probably under a cool climate, for the greenish arkoses and slates charged with carbon suggest cold rather than heat.

In the north-west volcanoes were active, but the east was comparatively free from eruptions. Both volcanic ash and ordinary clay and sand seem to have been spread out on the sea bottom in the Lake Superior region, and probably seaweeds throve in the mud. In the Grenville region the waters seem to have been clearer, and limestones were deposited on a very large scale, sometimes pure, but often muddy and mixed with a good deal of carbon, so that fucoids probably flourished here also.

If we reconstruct the conditions of the Keewatin we must then assume continents which have entirely vanished, on which weather, rain, and rivers worked, sweeping sediments down to the shallow or deeper seas to be spread out on a bottom which has also disappeared. The sediments and lavas and tuffs may be said to rest on nothing, for the once fluid or plastic Laurentian gneiss, cradling their synclines and pushing up from beneath them, could not have been the foundation on which they were laid down. Though the floor on which they once rested has nowhere been found, one may be certain that its materials included silica, alumina, and alkalies in the right proportions to fuse into a granitic magma, and this is practically all that is known of the pre-Keewatin world in Canada.

Rise and Fall of the Early Laurentian Mountains.

After the work of the volcanoes, of rain and frost and rivers, of winds and tides and currents, had piled up miles of rock in Keewatin times there came a great upheaval of mountains over thousands of square miles of the early Archæan surface. Possibly the earth was already shrinking through loss of volcanic material and of the steam and gases that exhale in eruptions. The Atlantic floor may have been settling down, thrusting inwards from the south-east, pushing up the weakened earth's crust beneath the shield into mountain rows; or it may be that some other cause must be sought for the somewhat haphazard domes which arose over such wide areas.

It may be suggested that the many thousands of feet of lava and stratified materials had so blanketed the lower-lying rocks that the heat from beneath crept up into them, softening and semi-fusing them, until in the slow lapse of time they began to flow sluggishly, ascending to form the wide-based domes of the Laurentian mountains. The source of the internal heat need not be discussed here. Uranium, with its various progeny, may have been as active then as now, or a more rapid axial rotation may have kneaded the discrete particles of a mass of planetesimals, and so warmed them up to the heat of fusion.

Then followed the deliberate and almost complete destruction of the great mountain system during a long period of time which has left no known Canadian record. The sediments derived from this destruction may have been piled on the bed of the Atlantic as it sank. It is possible that Sederholm's Bottnian in Finland may partially fill the gap.

Whatever disposal was made of the *débris*, several thousands of feet must have been carved from the mountains and swept out of view during the immense interval which separates the Keewatin and early Laurentian from the Lower Huronian, for the next series of rocks rests with a great discordance on the

upturned edges of the synclinally disposed Keewatin schists and the truncated domes of Laurentian gneiss.

The Huronian.

The Lower Huronian has very different relationships from the Keewatin. Where least disturbed, as north of Lake Huron and in the Cobalt region, the floor beneath it is often well preserved. Dr. Miller has shown that at Cobalt the surface of Keewatin and Laurentian was hilly or hummocky before the basal conglomerate of the Lower Huronian was deposited; and Professor Brock, in describing the Larder Lake district to the north, refers to 'the clean-swept and often rounded surface of the older rocks on which it is frequently laid down.' [1]

The basal conglomerate of the Lower Huronian contains pebbles and boulders of all the Keewatin and Laurentian rocks that went before, and among them are found beautifully striated stones. It is the oldest known boulder clay or tillite. The vast period of subaerial destruction that carved away the early Laurentian mountains ended in a glacial period, whose ice-sheets covered many thousands of square miles of North America, just as the last great period of peneplanation ended with the Pleistocene ice-sheets.

It is not a little impressive to see modern till resting on the Huronian tillite and including fragments of it as boulders. It is possible to break out from the modern glaciated surface stones whose underside received their polish and striæ in the Lower Huronian, while their upper surface has been smoothed and scratched by Pleistocene ice movements.

At Cobalt the tillite is accompanied by slate, which may be compared in all essential characters except hardness with the stratified clay of adjoining lake deposits of Pleistocene Age. The most recent and unconsolidated beds make clear the origin of some of the most ancient and, in appearance, most different rocks in the world.

In the Lake Huron region the action of ice was probably followed by an invasion of the sea, for the tillite is succeeded by thousands of feet of quartzite, arkose, and conglomerate, and by a few hundred feet of limestone. Possibly much or all of the limestones of the Grenville and Hastings series, which Dr. Adams reckons among the great limestone formations of the world, were formed at about the same time.

The Middle Huronian (Logan's Upper Huronian) is separated by a basal conglomerate, possibly glacial, from the Lower Huronian; but the break does not seem very profound, and the rocks do not differ much from those just described.

The least changed parts of the Huronian extend as a wide band for 200 or 300 miles north-east of Lake Huron, and in this area the uneven surface of Laurentian and Keewatin beneath the Lower Huronian boulder clay preserves for us a portion of the earliest dry land, the earliest peneplain known in America, and possibly in the world. This band has remained comparatively stable, while, so far as our information goes, all other parts of the Canadian Shield have undergone violent changes.

Rise of the Late Laurentian Mountains.

The Lower Huronian tillite has been found in many places throughout the Archæan region, over a stretch of 1,000 miles from east to west, and 700 miles from north to south; so that in all probability deposits like the Pleistocene till covered most of the surface.

Everywhere, however, except in the band extending north-east from Lake Huron, it seems to have been involved in later mountain building, and has been so sharply folded in with the Keewatin as to destroy the appearance of unconformity. It is instructive to note that so long and momentous an interval was entirely overlooked by geologists or treated as of small importance until a few years ago. There is usually no angular discordance to be observed, and the secondary schistose structures of Keewatin and Huronian are similar and parallel. The Huronian boulder conglomerate has often been rolled out to a schist in which only the harder boulders can be recognised as lenses; and sometimes even they are lost entirely, so that no evidence of discordance remains.

[1] *Bur. Mines, Ont.*, 1905, p. 31.

It is evident that the invasion of the later Laurentian granites and gneisses was accompanied by very important dynamic and metamorphic effects. Most of the batholithic domes of North-western Ontario are post-Lower Huronian, and date perhaps from the Middle Huronian or the interval between it and the Upper Huronian (Animikie).

The granites and gneisses of this second time of mountain-building have not been distinguished in mapping from those of the first in most places; and as they are both of precisely the same habit it will probably never be possible to separate them completely. Thus far both have been included under the name Laurentian, which must be considered as representing a lithological facies rather than a geological period. It may be, however, that the formation of batholithic mountains never really ceased from the end of the Keewatin to the end of the Lower Huronian. As the rocks called Laurentian are entirely eruptive, they should not be limited to a definite time, but only to a definite set of conditions as to composition, rate of cooling, and amount of pressure.

As in the earlier cycle, the period of mountain-building was followed by a period of destruction, ending in a peneplain of very wide extent.

The Animikie or Upper Huronian.

The interval between the lower formations and the Animikie is of great magnitude, perhaps even greater than that between the Keewatin and the Lower Huronian; and Lawson has suggested for it the name of the Eparchæan Interval. The Animikie has not been found resting on the Middle Huronian in Canada, so that this formation may partly bridge the chasm. Unless the Middle Huronian quartzites include part of the products of erosion we have no evidence as to the disposal of the many thousands of cubic miles of materials removed from the later Laurentian mountains.

The Animikie begins in most places with a thin basal conglomerate lying almost horizontally on the upturned edges of the previous schists and gneisses. Above this come chert, black slate, and other sediments, sometimes to the extent of 8,000 or 10,000 feet. The slate often contains carbon enough to make an important coal region if collected in definite beds.

The whole no doubt implies a transgressing sea, which ultimately must have covered a very large part of the Canadian Shield, since rocks of this age are found over wide surfaces north-west of Lake Superior, near Lake Mistassinni, in the heart of Labrador, on the east side of Hudson Bay, and near Great Bear and Dubaunt lakes. These rocks are found in Labrador up to 1,575 feet above the sea. This level, if extended in all directions, would submerge three-fourths of the Archæan peneplain.

At present these areas, though large, are widely separated; and it may be rash to assume that even soft, easily weathered rocks, like the Animikie slate, could have been completely removed from the intervening spaces. It is probable, however, that less than half of the Archæan then remained as dry land.

The Keweenawan.

There is an interval marked by a small discordance and a basal conglomerate between the Animikie and the Keweenawan, but the break in time was apparently not great. The two groups of rocks often occur together, though in many places the Keweenawan sediments overlap on to the Archæan, as in the neighbourhood of Lake Nipigon. Most of the Keweenawan sedimentary rocks are of shallow-water varieties, such as sandstone and conglomerate. At various places on the north-east shore of Lake Superior a coarse basal conglomerate is found as remnants preserved in small valleys or ravines in the granite. The ancient surface is now in process of resurrection by erosion, and the boulders once rolled on a Keweenawan shore are being freed from their matrix and once more set in motion by the waves of Lake Superior.

The Keweenawan, like the Keewatin, was a time of vigorous volcanic activity, and in most places the lava-sheets and laccolithic sills of diabase connected with their eruption far surpass the sediments in amount. The volcanic rocks are generally basic in character, and probably most of the diabase dykes widely found in almost all parts of the Canadian Archæan are of this age. The important

deposits of copper, nickel, and silver in Northern Canada are closely bound up with the Keweenawan basic volcanic rocks or with deeper-seated diabases probably of the same origin.

Here, as in the Keewatin, we are confronted with floods of basic lava coming up from unknown sources through the acid Laurentian gneiss. Do these basic lavas represent heavier segregations settling to the bottom during the slow movements of the granitic magma as it climbed into the Archæan batholiths? One might imagine these heavier and more liquid parts sinking beneath the lighter, more viscid, magmas of the domes, and remaining fluid until the mountain masses above had become completely solid. The supposed thrust from the Atlantic basin to the south-east might then bring strains to bear on the solid crust, more or less shattering and shifting its masses, squeezing up the still molten diabase through all the fractures and pores.

Several remarkable basins were formed in the Archæan peneplain by the ascent of these lavas, permitting the massive roof which formerly covered them to collapse by block faulting or by the formation of an irregular syncline. The basin of Superior seems to be of this nature. It is still rimmed by the Keweenawan lavas, sometimes accumulated to the thickness of 50,000 feet. Just to the north is the smaller basin of Lake Nipigon, with its edges and islands of diabase sheets; and to the east, near Sudbury, is the extraordinary synclinal basin, with which the great nickel mines are connected. These basins seem to have resulted from the collapse of the solid crust because of the removal of support when basic eruptives ascended from beneath.

Palæozoic History.

The exact relation of the Keweenawan to the Cambrian is somewhat in doubt, though most geologists make it pre-Cambrian. The St. Mary's, or Lake Superior, sandstone, which rests upon the Keweenawan with a slight discordance and overlaps upon the Archæan, is generally called Cambrian; it contains no fossils and occurs only along the shores of Lake Superior and St. Mary's River, so that its position in time is uncertain.

Potsdam sandstone, either Upper Cambrian or Lower Ordovician, rests upon the planed-down Archæan surface at the Thousand Islands and other points in Eastern Canada, often with a conglomerate at its base; and undoubted Ordovician limestones feather out upon the Laurentian all the way from Saskatchewan and Manitoba on the north-west through Ontario to the city of Quebec on the east. These limestones represent an important transgression of the sea upon the Canadian Shield. Apparently the old hummocky surface was often pretty cleanly swept, so that limestone with very little fragmental material, rests immediately upon the gneiss, but in other cases there is arkose or a basal conglomerate of Laurentian materials.

Occasionally Archæan hills rise island-like through the shaly limestone, which tilts away quaquaversally, as if the hill had protruded through the sediments. This appearance is probably due to the settling and shrinking of the mud in its consolidation to rock. Drill-holes east of Lake Ontario show that there were valleys hundreds of feet deep between these Archæan hills, so that in this region the peneplain was far from complete. These inequalities may be considered foothills of the Adirondack mountains further east.

There is reason to believe that before the close of the Ordovician the sea crossed from the region of Lake Winnipeg to Hudson Bay, flooding all the lower parts of the shield; but probably most of Labrador and part of Franklin, north-west of Hudson Bay, remained as dry land.

The Silurian follows on the Ordovician without a discordance, and at this time the sea probably submerged an even larger part of the shield, since the Silurian limestone of James's Bay is only 250 miles from that south of the Great Lakes, and there are two outliers between—on Lakes Nipissing and Temiscaming. It may be added that the highland of Silurian limestone crossing Southern Ontario, with a bold escarpment facing north-east, rises hundreds of feet higher than the watershed towards Hudson Bay. The escarpment facing the Archæan 'old land' corresponds to the Scandinavian 'glint,' and has a similar relation to the lakes of the Archæan border.

The Devonian Sea also encroached south of James Bay and along the south-west side of the shield from Clear Lake, in Saskatchewan, to Great Bear Lake.

What took place on the Archæan continent while the coal forests flourished on the lowlands to the south and to the far north is unknown, since no carboniferous rock has been found on its surface.

Mesozoic and Cenozoic History.

Early Mesozoic times are a blank, but a few small outcrops of Cretaceous rocks resting on the Archæan toward the south-west show that portions of its rim were once more under water. Dr. Wilson believes that an important facet of the peneplain should be dated from the Cretaceous, since planation was going on in parts of the United States at this time; but no positive evidence of this is at hand.

Nor is there any evidence as to its history in the tertiary before the oncoming of the Ice Age of the Pleistocene, when its whole surface was scoured more than once by great glacial sheets. The mantle of decayed rock which must have accumulated during the long dry land stage was almost completely swept away, leaving the rounded surfaces of ancient rock fresh and clean beneath the boulder clay.

In an important inter-glacial interval and in post-glacial times much of the morainic material was assorted in great lakes whose shore and deep water deposits cover large parts of the surface. With the departure of the ice the sea once more transgressed upon the lower parts of the shield, but the land has been rising since, leaving a belt of marine deposits up to about 500 feet around the shores of Hudson Bay, the St. Lawrence, and the Atlantic.

How much of the Shield has been Covered?

It is generally stated that the Canadian Shield has been dry land since the Archæan, and hence that erosion has been taking place ever since that time. This is probably true for part of the north-eastern portion of the shield and perhaps also the north-western, but much of the area, especially toward the south, was buried in early days under Palæozoic sedimentary rocks, and so protected from further destruction. These sediments are still being slowly stripped from the Archæan in many places.

This may account for the greater proportion of Huronian and Keewatin rocks in the south as compared with the north. It is probable that in the unprotected northern parts weathering agencies have eaten the higher Archæan rocks completely away from the Laurentian gneiss beneath. Before asserting this positively, however, it may be well to await more thorough exploration of the little known north.

It is possible, but not very probable, that the whole area was at one time covered with Ordovician or Silurian shale and limestone. If so, all traces of this capping have been removed from hundreds of thousands of square miles of its surface.

There is one very impressive feature of the Archæan as found beneath the later rocks. The peneplain, with its rounded, hummocky surface, seems exactly the same when one strips from it recent boulder clay, early Palæozoic shale or sandstone or limestone, Keweenawan eruptives, or even Lower Huronian tillite, where this has remained undisturbed. It is as though all the millions of years of destruction since the Middle Palæozoic had made only unimportant changes in the pre-Cambrian peneplain. When it is recalled that peneplanation took place twice in the pre-Cambrian, before the Lower Huronian and before the Animikie, one is almost driven to think that pre-Cambrian time is far longer than post-Cambrian.

Relation of the Shield to the Palæozoic.

Except toward the east, the Canadian Shield sinks gently beneath Palæozoic beds, in most cases retaining its character as a peneplain. How far does it continue to the south and west beneath the sedimentary rocks, and to what depth does it extend?

The results of drilling at Toronto, 80 miles south of the contact, show gneiss and crystalline limestone at a depth of 1,200 feet below the surface, or 940 feet below sea-level. Near Lake Erie, 130 miles to the south of the contact, the Archæan is reached at a depth of 3,300 feet—2,700 feet below sea-level. Its slope to Toronto is at the rate of 20 feet per mile, and from Toronto to Lake Erie at the rate of 35 feet per mile. This corresponds fairly well with the dip of the overlying Palæozoic rocks.

As the peneplain rises more than 1,300 feet above sea-level at the watershed 300 miles north of Lake Erie, there is a difference of 4,000 feet in a north and south direction; and if comparison is made with the Adirondack Mountains 250 miles to the east the difference even amounts to 6,600 feet. It is probable, however, that the Adirondacks were a residual group of mountains never reduced to the general peneplain level. It is clear that the pre-Palæozoic peneplain has been greatly warped in later ages, perhaps as a result of the increasing load of sediments piled on its southern edge.

One is apt to think of these ancient crystalline rocks as an exceedingly solid and resistant block of the earth's crust, likely to undergo little deformation: so that this evidence of warping or doming of the surface comes as a surprise. In reality shiftings of level under changes of load are normal in every region, and have been going on along the southern border of the Canadian Shield all through Pleistocene times, and perhaps continue now.

The proof of this is to be found in the differential elevation of the shore-lines of the great post-glacial lakes, which ascend with an increasing grade toward the north (N. 20° E.). In the case of Lake Iroquois the difference in level between the two ends of the earliest shore is more than 500 feet, and the grade toward the north even rises to six or seven feet per mile. If we add 230 feet of deformation of the marine beaches, which followed Lake Iroquois toward the north-east after the final melting of the ice, there is a known change of level amounting to 730 feet within late Pleistocene times. There is reason to believe that similar changes of level took place during the inter-glacial period recorded at Toronto and to the north.

The Pleistocene sinkings and risings are naturally accounted for by the piling up and removal of the thousands of feet of ice in the Glacial Periods, though probably isostatic equilibrium was not reached in these movements.

We know that the ice was more than 4,000 feet thick, since it passed over the tops of the Adirondack mountains. This thickness of ice is equal in weight to about 1,600 feet of rock, while the greatest known elevation since the removal of the load is not much more than 700 feet, implying that a weight of 900 feet of rock can be supported by the shield. It may be, however, that in the interior of Labrador, where no beach-lines give evidence as to changes of level, the doming is much greater than the amount suggested.

It is of interest to note that these adjustments to change of load take thousands of years to accomplish. The rise due to the melting of the Labrador ice-sheet may be going on slowly now, thirty or forty thousand years after the load was lifted.

These sinkings and risings must be accomplished by plastic flow outwards from beneath the loaded area or inward toward the area relieved of its load.

Instead of a rigid, unyielding shield, we must conceive a stiffly flexible covering over a plastic substratum, where during thousands of years adjustments of level, amounting to hundreds of feet, may take place; and during millions of years of removal of load by erosion, or of piling on of load through sedimentation, changes of level of thousands of feet can be accomplished. Such changes have taken place on the southern and western sides of the shield without any known rupture, while on the east the adjustment has been accomplished in part by great faults.

Has the Archæan, which is supposed to underlie the stratified rocks in all parts of the world, undergone the same vicissitudes?

Summary.

The history of the Canadian Shield begins in pre-Keewatin times, with land surfaces on which weathering took place, and seas in which mud and sand were deposited. If the earth were ever molten, that stage had long been passed before

the Keewatin sediments were laid down, for they include carbon probably derived from fucoids, which could not have lived in a hot sea.

The pre-Keewatin land surfaces and sea bottoms have totally disappeared, so far as known to Canadian geology. Apparently they have been fused and transformed into the gneisses of the Laurentian.

The Keewatin was a time of great volcanic activity, lava streams and ash rocks surpassing in amount the thick sheets of sediments. At the end of the Keewatin the thousands of feet of volcanic and clastic rocks were lifted as domes by the up-welling of batholiths of early Laurentian gneiss.

Then followed a profound gap in the record, during which the mountains were levelled to a hummocky peneplain. This gap represents a very long period of weathering and destruction on a land surface, ending in glacial action on a large scale.

The Lower Huronian begins with the deposit of a thick and widespread boulder clay, followed up by a transgression of the sea in which mud and sand, and also limestone and chert, were deposited.

After a short break similar processes went on in the Middle Huronian. During the Middle Huronian, or in the interval between it and the Upper Huronian (Animikie), mountain-building was renewed on a grand scale, many synclines of Keewatin and Lower Huronian rocks being caught between the rising batholiths of late Laurentian gneiss. A broad central band of the Lower Huronian escaped this process, however, and has preserved its original attitude on a floor of Keewatin and Laurentian.

The Animikie or Upper Huronian sediments which rest on the planed-down floor of upturned Lower Huronian, Laurentian, and Keewatin rocks consist largely of chert and carbonaceous slate or shale, which lie nearly horizontal and have undergone very little change.

The Keweenawan follows the Animikie with only a small break, and includes shallow water-beds of sandstone and conglomerate, accompanied by immense outflows of lava. As a result of the outpouring of lava great basins, like that of Superior, resulted. It is probable that during the Animikie and Keweenawan most or all of the Canadian Shield was covered by the sea.

The Keweenawan is generally held to mark the close of the Archæan (or Algonkian or Proterozoic). Low reports portions of these formations as having been caught in mountain-building of the Laurentian type in Labrador, but commonly they have not been disturbed.

During early Palæozoic times the Canadian Shield was more than once encroached upon by the sea, though probably much of the peninsula of Labrador, and perhaps a region north-west of Hudson Bay, escaped.

From the Devonian to the Pleistocene the shield seems to have remained dry land, and part of the Ordovician and Silurian capping of sediments was removed during this long period.

The succession of Pleistocene ice-sheets completed the work of denudation, and at the end of the Ice Age many thousands of square miles of the lower portions were once more beneath the sea.

Last of all, the region has been rising at unequal rates in different parts, as shown by the warping of marine and fresh-water beaches.

The surface of low hills and rounded knolls of gneiss and schists beneath the Pleistocene boulder clay resembles in every way that beneath the flat shales and limestones of the early Palæozoic, or the nearly horizontal sediments of the Animikie, or even the undisturbed parts of the Lower Huronian boulder clay. It may be that much of the surface has been covered with sediments and restored to daylight by subaerial erosion several times in succession. The greater part of the carving-down seems to have been done before the Animikie—*i.e.*, within pre-Cambrian times—and the pre-Huronian surface seems as mature as any of the later ones. The bearing of this on the length of early geological time is evident. Pre-Huronian time includes the laying down of thousands of feet of Keewatin sediments, the elevation of early Laurentian mountains, and the levelling of these mountains to a peneplain. It may be as long as post-Huronian time.

The following Papers were read :—

1. *The Yoredale Series and its Equivalents elsewhere.* *By* COSMO JOHNS.

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2. *Notes on the Lower Palæozoic Rocks of the Cautley District, Sedbergh, Yorks.* *By* J. E. MARR, *Sc.D., F.R.S., and* W. G. FEARNSIDES, *M.A., F.G.S.*

The general succession is well known. The following additions to our knowledge of the various divisions have been recently obtained by us :—

Salopian.—Divisible into Lower Ludlow rocks (Bannisdale slates, Coniston grits, and Coldwell beds) above, and Wenlock rocks (Brathay flags) below. The calcareous gritty flags with *Phacops obtusicaudatus* are found here at the base of the Coldwell beds, and form a ready line of separation between the Ludlow and Wenlock graptolitiferous strata. The Salopian graptolitic zones are being worked out by Miss G. R. Watney and Miss E. G. Welch.

Valentian.—The succession as described by one of us with the late Professor Nicholson was incomplete. We have now found a section in Watley Gill which nearly completes the sequence. In that beck the *Monograptus argenteus*, *M. fimbriatus* and *Dimorphograptus* zones of the Skelgill beds are found with their intercalated trilobite beds, the higher graptolitic zones being absent owing to a fault which repeats the *Dimorphograptus* beds. The *argenteus* zone contains the type fossil and its usual associates, and exhibits the 'green streak' seen in the Lake District and in North Wales.

Ashgillian.—The Ashgill shales have long been known here. The basal *Staurocephalus* limestone appears to be represented by a greyish argillaceous limestone in Taith's Gill, which succeeds the Caradocian rocks with perfect conformity, and yields abundance of *Remopleurides radians* and other fossils; also by a similar limestone in the same position in Backside Beck, with badly preserved trilobites, &c.

Caradocian.—Black calcareous shales with their argillaceous limestones containing a very rich Caradocian fauna, recalling that of the Trinucleus shales of Sweden. The fauna is being worked at and separated from that of the Ashgillian beds.

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3. *The Graptolitic Zones of the Salopian Rocks of the Cautley Area near Sedbergh, Yorkshire.* *By* Miss G. R. WATNEY *and* Miss E. G. WELCH.

We have obtained the following zones in the Ludlow rocks in descending order :—

1. *Monograptus leintwardinensis* (Hopk.)	Lower Bannisdale Slates
2. *Monograptus Nilssoni* (Barr.)	Coniston grits U. Coldwell beds
3. *Monograptus vulgaris* (Wood)	M. Coldwell beds

In the Wenlock the following zones have been found in descending order :—

1. *Cyrtograptus Lundgreni* (Tullb.)	L. Coldwell beds Brathay flags
2. *Cyrtograptus Linnarssoni* (Lapw.) *Cyrtograptus symmetricus* (Elles)	Brathay flags
3. *Monograptus riccartonensis* (Lapw.)	Brathay flags
4. *Cyrtograptus Murchisoni* (Carr)	Brathay flags

These zones are comparable with those discovered by Miss Elles [1] and Mrs. Shakespear [1] in Wales and the Welsh Borderland [1]; though we have not yet succeeded in finding all the zones which they record we hope shortly to establish them in this area.

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[1] *Quart. Journ. Geol. Soc.*, 1900.

4. *Pleochroic Halos.* *By* Professor J. Joly, *F.R.S.*

An account of recent advances in the radioactive theory of the formation of halos, and of evidence as to the chemical nature of the deposit occasioning the halo.

5. *Outlines of the Geology of Northern Nigeria.* *By* Dr. J. D. Falconer, *M.A.*, *F.G.S.*

The Protectorate of Northern Nigeria lies for the most part between Lake Chad and the confluence of the rivers Niger and Benue, and comprises an area of about 255,700 square miles. Crystalline rocks are exposed over about half of this area, and among them two series have been recognised: (1) a series of hard, banded, and much granitised gneisses of an Archæan type; (2) a series of quartzites, phyllites, schists, and gneisses of sedimentary origin with associated amphibolites, hornblende schists, and other more or less metamorphosed igneous rocks. The two series, which were probably originally unconformable, have been folded together along axes which are predominantly meridional in direction. They have also been pierced by numerous igneous intrusions, which are readily subdivided into an older and a younger group. The older group consists principally of granites, wholly or partially foliated, which have been affected to a varying extent by the forces which produced the metamorphism of the gneisses and schists. The members of the younger group are non-foliated, and include such types as tourmaline granite, riebeckite granite, augite syenite, augite diorite, and numerous associated dyke rocks.

Rocks of Cretaceous Age are found in the valleys of the Benue and the Gongola and in the angle between the two rivers. They are invariably gently folded and sometimes broken and faulted, and consist of a lower series of sandstones and grits, in part salt-bearing; and an upper series of limestones and shales, with numerous fossils of Turonian Age. The post-Cretaceous rocks, which rest unconformably upon the Cretaceous limestone, and are probably all of Eocene Age, occur over three detached areas: (1) in Sokoto province and the Niger valley, (2) in Bauchi and Bornu, and (3) in Yola. The Sokoto series, which contains marine intercalations yielding abundant Eocene fossils, is continuous southward with the sandstones, grits, and ironstones of the Niger valley. The correlation of the sandstones, grits, and clays of Bauchi, Bornu, and Yola with the Eocene rocks of Sokoto and the Niger valley is based partly upon lithological similarities and partly upon the absence of evidence of any extensive post-Eocene submergence of the Protectorate.

Extensive fields of basaltic lava occur in Southern Bornu and on the borders of Bauchi and Nassarawa; and numerous puys of trachyte, phonolite, olivine basalt, and nepheline basalt are distributed throughout Southern Bauchi, Muri, and Yola. The puys and lava fields alike are the product of Tertiary volcanic activity.

During the latter part of the Tertiary period there appear to have been repeated minor oscillations of the crust, which culminated in the elevation of the Bauchi plateau and the Nassarawa tableland, the depression of the Chad area, and the establishment of the present river system.

6. *Notes on Natal Geology.* *By* Dr. F. H. Hatch, *F.G.S.*

Excepting the Cretaceous rocks, which only attain to a quite unimportant development on the coast, there are three distinct formations which, separated by great unconformities, take part in the geology of Natal. These are:—

The Karroo System (Carboniferous to Jurassic).

The Table Mountain Sandstone (Devonian).

The Metamorphic Basement Rocks (Swaziland or Archæan).

The horizontal beds of the Karroo System are of enormous thickness, and extend over the greater part of the colony, from the Drackensberg to near the east coast. Near the summit of the scarp of the Drackensberg they consist of the Stormberg lavas and tuffs. These are underlain by the other divisions

of the Stormberg—the Cave Sandstone, Red beds, Molteno beds, &c.—while the base of the scarp and the foot hills are composed of the Beaufort mudstones and of the Ecca sandstones and shales, the Ecca sandstones carrying the coal resources of the colony. The Dwyka Conglomerate forms the base of this system, the underlying old rocks being frequently grooved and polished by ice-action.

A big unconformity separates the Karroo rocks from the Table Mountain sandstone, which has been eroded often to a comparatively thin bed of conglomerate, or even completely removed before the deposition of the Karroo beds. It has, however, retained the horizontal position in which its beds were first deposited, and forms several typical table mountains, as Table Mountain, near Pietermaritzburg, Kranzkop on the Tugela, and Nkomo in Zululand. In this respect it contrasts sharply with the underlying metamorphic schists and quartzites of the Swaziland System, which are folded into well-marked anticline and synclines, and almost invariably present a steeply inclined outcrop. These metamorphic rocks comprise quartzites, ferruginous jasperoid rocks, conglomerates, and mica, chlorite, kyanite, and hornblende schists, and are in places invaded by intrusions of granite and permeated by veins of aplite and pegmatite. These old rocks, which are probably equivalent to the Archæan, appear wherever the rivers have deeply incised their valleys, and as this can only occur in the lower part of the river-courses, the outcrops are confined to the easterly portion of the colony—for instance, in Zululand in the valley of the Tugela, in the gorges of the Buffalo, in the cañon-like valley of the Msuzi, and in the Umhlatuzi and Umfuti valleys.

But between these valleys, even in Zululand, great piles of Karroo strata still remain, as, for instance, those forming the Umsinga, Oudeni, and Kala Mountains, where the horizontality of the stratification is brought into strong relief by the presence of great sills of dolerite.

Although the base of the Karroo occurs near Pietermaritzburg at an elevation of 3,000 feet above the sea, Ecca shales and Dwyka conglomerate are also found at sea-level on the coast at and south of Durban. This can only be explained, as pointed out by Suess, by the assumption of the existence of a great N. and S. fault, the train of which lies considerably east of the present scarp of the Drackensberg. The latter has been, and is still being, pushed to the west by the erosion of the Natal rivers, which practically all take their source on its slopes and flow eastward to the Indian Ocean.

FRIDAY, SEPTEMBER 2.

Joint Meeting with Section E.—See p. 652.

MONDAY, SEPTEMBER 5.

The following Report and Papers were read :—

1. *Report of the Seismological Committee.*—See Reports, p. 44.

2. *The Geolog of Cyyrenaica. By* Professor J. W. GREGORY, *D.Sc., F.R.S.*

3. *An Undescribed Fossil from the Chipping Norton Limestone. By* MARMADUKE ODLING.

4. *The Glaciated Rocks of Ambleside.* *By* Professor Edward Hull, *LL.D., F.R.S.*

I visited Ambleside in the beginning of August in order to ascertain the condition of the remarkable glaciated rock-surfaces which are to be seen there. I first visited Ambleside in 1862, when I noticed the well-known form of this rock, exhibiting on its smoothed surface the parallel groovings characteristic of rocks over which the ice of a glacier had formerly passed. The rock, formed of indurated grit and slate, presented the characteristic 'crag-and-tail' form, pointing to the direction, nearly magnetic north, up the valley of the Rothay, from which I gathered that the glacier had descended from Helvellyn and the neighbouring heights forming the central ridge of the Lake District. This view was confirmed after an examination of several other valleys and mountains; and the results were published in the 'Edinburgh New Philosophical Journal.' There are other ice-eroded bosses of rock rising out of the valley as well as from the surface of Lake Windermere. But it is seldom that glacial striæ can now be observed, owing to the effects of weather-action, so that the Ambleside rock is of peculiar interest from the freshness of its surface. The sketch which accompanied my paper was reproduced by Sir Charles Lyell in his 'Antiquity of Man' as evidence of the former presence of glaciers in the Lake District of England.

I attribute the freshness of the rock-surface and its striations to the fact that, when the ground was being cleared for the foundations of the modern church which occupies a site here, it was partially covered by a coating of boulder clay or moraine matter, by which the surface was protected from atmospheric waste and erosion.[1] This covering was probably removed, leaving bare the rock, which, owing to its peculiar form, was left undisturbed. Considering that steps should be taken with a view to the preservation of this natural monument, I consulted the Rev. J. Hawkeswith, vicar of the parish, who promised to consider the possibility of effecting this object. These memorials of the Glacial Period are yearly disappearing. Boulders and erratic blocks are being broken up for building purposes; moraines are being cleared away or laid down in pasture-land, or for agriculture or building; and the striæ and grovings of the rock-surfaces are being covered over or worn down by traffic. It is, therefore, of great importance that their presence should be recorded on maps, or that their remains should, as far as possible, be preserved intact.

5. *The Shelly Moraine of the Sefström Glacier, Spitsbergen, and its Teachings.* *By* G. W. Lamplugh, *F.R.S.*

The Sefström Glacier when first mapped by Professor De Geer in 1882 had its sea-front two or three miles back within its side-valley, and was flanked on both sides by fluvio-glacial outwash plains. Between that time and 1896, when it was again examined by Professor De Geer, it had advanced about four miles, burying the outwash plains, filling its valley up to the mountain slopes, and bulging out into Ekman Bay in a broad lobe that reached across to Cora Island, hardly a mile from the opposite shore of the bay. But already in 1896 it was sinking back; and when visited in 1908, though its detached snout still hung grounded on Cora Island amid huge masses of morainic material, the main front had so far receded that there was again a sea-passage between it and the island, and a narrow strait, with ice-cliffs to right and left, between the new front and the detached portion affixed to the island. Since then there has been further recession, so that this year (1910) we found a wider passage; but a remnant of the melting snout still shone up conspicuously amid the red moraine on Cora Island.

In its original condition Cora Island was a low spit about two miles long and half a mile or more wide, composed of Carboniferous limestone partly covered with raised beach; but it has been increased to more than twice its size by the moraine banked upon its western side during its invasion by the glacier. This moraine, which for the greater part must have been actually under the ice at its maximum, has been thrown in a tumultuous succession of ridges and hollows

[1] The boulder clay can be seen resting on the rock alongside a footpath on the north side of the churchyard.

across the flank of the island, forming a curved belt about three miles long, nearly half a mile wide at its broadest, rising in places to 50 or 60 feet above sea-level, and ending sharply, where it touches the original island, against the lower bare ground, with hardly any 'outwash.' It consists almost entirely of streaky red clay containing a few scratched boulders, and crowded with marine shells, some broken, but most of them perfect and the bivalves united. The clay has evidently been derived, in the first place, from the red Devonian rocks into which the fiord is cut; but its more immediate origin was the neighbouring sea-bottom, which has undoubtedly been dragged up in some way by the glacier in its advance. The existing remnant of the glacier was seen to be curiously entangled among the clay, and the presence of smaller masses of ice buried under the moraine was indicated by the crater-like hollows of subsidence by which its surface was pitted.

These facts show clearly that (1) material similar to some English boulder-clays may form the *terminal* moraine of a glacier; (2) a glacier advancing over a sea-bottom may incorporate marine detritus abundantly in its moraine; (3) banks of boulder-clay may terminate abruptly and with a sharp boundary on bare unglaciated land; (4) material in the path of an advancing glacier may be uplifted sharply on a rising slope. The possibility of these events has been frequently doubted but is here proved.

Joint Meeting with Sub-section B (Agriculture).—See p. 585.

TUESDAY, SEPTEMBER 6.

The following Papers were read :—

1. *The Cause of Gravity Variations in Northern India.* *By* Professor Sir THOMAS H. HOLLAND, *K.C.I.E.*, *D.Sc.*, *F.R.S.*

Among the gravity variations indicated by the plumb-line and pendulum observations conducted in India the most conspicuous is the band of high gravity, first detected by Colonel S. G. Burrard, R.E., F.R.S., stretching from about Kisnapur (latitude 25° 2′, longitude 88° 28′) in Bengal to a point between Ferozepore and Montgomery in the Punjab (latitude 30° 50′, longitude 74° 30′).[1] The direction of this band of high gravity parallel to the general trend of the silt-filled Gangetic depression, the great Himalayan folds which have developed since Lower Tertiary times, and the pre-Tertiary shore line between Gondwanaland and the great Eurasian Ocean suggests a genetic relationship between these four features. With these may be correlated the general trend of faulting during pre-Deccan Trap times in what is now the Central and Northern part of Peninsular India. A general east-west trend is shown by the faults which affect the Vindhyans and are of older date than the Permo-Carboniferous; by the later faults which affect the Lower Gondwanas and are of earlier date than the Trias; and by the still younger faults that disturb the Upper Gondwanas of Triassic and Jurassic Age. In the same area there is a general tendency for the dykes of Deccan Trap Age (Upper Cretaceous) to follow an east-west direction. These faults and also the fissures into which the basic rock was injected were formed throughout the period during which, from Lower Palæozoic to Upper Mesozoic times, there was a continual denudation, with consequent relief of load, from the Gondwana continent, and a corresponding loading with accompanying, if not consequent, depression of the adjoining ocean bottom immediately to the north of the line now occupied by the crystalline, snow-covered peaks of the Himalaya. The persistence of this process must have resulted in a stretching of the continent in a general north-south direction, as shown by the transverse normal, or tension, faults. The process culminated with the great out-welling

[1] See Burrard, *Phil. Trans.*, A, vol. 205, 1905, pp. 289-318; Lenox-Conyngham, Survey of India, Professional Paper No. 10, 1908.

of the Deccan Trap towards the end of Cretaceous times, and thereafter followed the depression of the Gangetic belt with the folding up of the Himalayan range.

As the Deccan Trap spread in thin sheets over large areas, it presumably came out in a high degree of fluidity and with a high temperature, while its mass was too great for its eruption to be due to fusion by accidental local causes. It is thus justifiable to assume, as the most probable of hypotheses, that it represented the outwelling of the persistent, subcrustal, basic magma, which is assumed by many on other grounds to exist in a state of fluidity, or potential fluidity, at about 30 to 50 miles below the surface.

It has been asserted that Dutton's theory of isostasy necessarily incurs a perpetuation of the process of increasing depression in the area being loaded, and of continued uprise in the adjacent area which is exposed to denudation. But if my deduction as to the origin of the tension faults in Peninsular India be justified, and if the Deccan Trap outburst was caused by the culmination of this process, we have an instance which shows that isostasy can come to an end in suicidal fashion, and thus a formidable objection to Dutton's theory is removed.

By borrowing an idea ably expounded in a series of papers by Professor R. A. Daly, of Massachusetts, we have also, with the facts briefly indicated above, a reasonable explanation of the Gangetic depression and of the heavy band which underlies the alluvium in a direction parallel to the tension faults further south. Professor Daly assumes that under favourable circumstances the sub-crustal gabbroid magma may enter the shell of tension, which has been postulated by Mellard Reade, C. Davison, G. H. Darwin, O. Fisher, and M. P. Rudski to exist usually below the superficial shell of compression. He also shows, from purely mechanical considerations, that intrusions into this shell tend to expand into batholiths, and, by reducing the tension, tend to pull down the surface into marked geosynclines.[1] If now we assume that in the northern part of Peninsular India the stresses during Palæozoic and Mesozoic times were predominantly in a north-south direction, as indicated by three generations of precretaceous, normal faults, we may likewise assume the production of basic batholiths with a general east-west alignment in Northern India. These deep-seated masses of basic (or probably ultra-basic) rock are suggested as the cause of the subterranean band of high gravity as well as of the Gangetic depression; the withdrawal of the material forming the batholiths may account also for the deficiency of gravity under the visible Himalaya as well as for some distance southward under the plains along the foot of the range. A similar, though possibly less pronounced, distribution of gravity should on this theory be found along the Indus valley to the south-eastwards of the Baluchistan folds.

2. *Discussion on the Concealed Coalfield of Nottinghamshire, Derbyshire, and Yorkshire.*

(1) *On the Concealed Portion of the York, Derby, and Nottingham Coalfield. By* Professor Percy Fry Kendall, *M.Sc., F.G.S.*

This great coalfield is a basin of which only the western moiety is exposed, the other part being concealed by a discordant cover of Permian and later rocks. Many attempts had been made to define the limits of the concealed extension, but these were based upon no principle. When the author was invited to report upon the question to the Royal Commission on Coal Supplies in 1905 his attention had already been directed to a possible solution of the problem by reference to the remarkable attenuation of the Jurassic and Lower Cretaceous sequence in the tract of country about Market Weighton. Here the rocks that, in the Cleveland area and on the coast to the north of Flamboro' Head, attain a thickness of upwards of 3,000 feet are reduced by failure of deposition or by

[1] See especially Professor Daly's paper 'Abyssal Igneous Injection as a Causal Condition and as an Effect of Mountain-Building,' *Amer. Journ. Sci.*, xxii., 1906, 195-216.

successive unconformities to 100 feet of Lower Lias. As this great hiatus occurs in exact alignment with the northern edge of the coalfield, it is probable that it marks a series of 'posthumous' movements of the pre-Permian fold by which the coalfield was defined.

By a similar line of argument the southern boundary is connected with the Charnwood axis, whose posthumous effects are seen in the dying out of certain of the Mesozoic rocks, *e.g.*, the Kimmeridge Clay near Cambridge. The eastern margin is altogether more problematical. It may possibly be indicated by an anticlinal fold near Willoughby and Louth in Lincolnshire, but no practical importance attaches to the determination of the point, as the Coal Measures in any case would be out of reach of the miner.

Since the Report of the Commission was published borings have been put down at Newark, near Thorne, and near Selby that have proved the existence of Coal Measures at those places, and have so far confirmed the conclusions in the Report; and I am now permitted to announce that a boring that is now being put down at Scunthorpe, on the eastern bank of the Trent, has also proved Coal Measures, and thus carries the proved coalfield another eleven miles to the east.

(ii) *The Coal Measures of the Concealed Yorkshire, Nottinghamshire, and Derbyshire Coalfield.* *By* WALCOT GIBSON, *D.Sc.*

On the map accompanying Mr. Currer Brigg's Report on District D in the Final Report of the Royal Commission on Coal Supplies for 1905, a triangular area having its apex at the Haxey (S. Carr) boring is marked off as the proved extent of the concealed coalfield. The area thus defined amounts to about 460 square miles. To this, as the result of information obtained from several borings for coal completed since 1905, there can be added about 200 square miles situated north-east of Haxey and about 200 square miles lying south-east of Haxey. Much information has also been collected in the proved coalfield. The new material, so far as it relates to the Coal Measures, may be considered under (1) shape of the Palæozoic floor, (2) character of the measures, (3) the workable seams that are likely to occur within 4,000 feet depth, and (4) their probable extension beyond the limits considered as proved in the Report of 1905.

1. *Palæozoic Floor.*—Between the outcrop of the Magnesian Limestone and the River Trent, north of Nottingham, the Permian rests on a uniform plain with a slope not exceeding two degrees and having a general direction to the east or a little north of east. Over the faulted area, south of Nottingham, the uniformity of slope has been broken; but outside the faulted belt the same even surface is maintained between Ruddington, Edwalton, and Owthorpe.

2. *Character of the Measures.*—The Barlow (Selby) boring in the north, the Thorne boring in the east, and that of Owthorpe in the south show that the Coal Measures immediately beneath the new formations belong to an horizon several hundred feet above the Top Hard or Barnsley Coal, which is a high and most valuable seam in the coalfield. In these measures a marine band (20 to 50 feet thick) lies between 520 feet (Oxton boring) and 629 feet (Mansfield Colliery) above the Top Hard Coal in Nottinghamshire, and, as ascertained by Mr. Culpin at Brodsworth and Bentley and by Mr. Dyson at Maltby, between 670 and 705 feet above the Barnsley Coal in Yorkshire. The fauna, exclusively marine, is represented by fifty species distributed among thirty-seven genera. Many of the forms occur in the shales below the Millstone Grits, and a few represent survivors from the Carboniferous Limestone. The persistence, thickness, and fauna of the bed indicate a general and a fairly prolonged incursion of the open sea during late Middle Coal Measures. Minor incursions are represented by a few thin beds occurring above and below this horizon in Nottinghamshire and Yorkshire.

The thickness of the measures as a whole increases to the north and diminishes to the east.

3. *The Workable Seams.*—All the borings and sinkings strike Coal Measures above the chief marine bed; but, except at Oxton and Maltby, both situated in the proved coalfield, the Upper Coal Measures have been completely removed by pre-Permian denudation. The seams above the Top Hard Coal and Barnsley Coal

are irregular in their occurrence and of uncertain quality. In the Doncaster and Thorne area the Dunsil Coal 50 feet below the Barnsley bed appears to be a valuable seam, but it deteriorates south of Doncaster. Most of the lower coals over the recently proved extension of the coalfield lie beyond the limit of profitable working. The future resources of the coalfield therefore mainly depend upon the thickness, quality, and depth of the Top Hard or Barnsley Coal.

Extension.—As a result of the explorations made since the Report of 1905 the proved limit of the concealed coalfield may with some confidence be extended to a line joining Selby, Thorne, Haxey, and Owthorpe, but the quality and thickness of the coal cannot be foretold. There is no conclusive evidence to show whether, north of Thorne, the Barnsley Coal will take on the inferior character which it assumes north-east and east of Wakefield under the name of the Warren House Coal, and whether the thinning out of the Top Hard Coal observable in some of the collieries south of Mansfield will continue to the east.

A further extension north of the Ouse, east of the Trent, and south-east of Owthorpe is probable, but it is important to bear in mind how much there must be of conjecture in any conclusions arrived at from the slender evidence at present available.

3. *Marine Bands in the Yorkshire Coal Measures.* *By* H. Culpin.

Until recently the records of marine fossils in the Yorkshire Coal Measures, except from the lowest beds, were very meagre. Five bands containing them were known, two (the roof of the Thin coal, and the Pecten bed forming the roof of the Gannister coal) being near the base of the Coal Measures, one about 80 feet above the Silkstone coal, and two above the Shafton coal.

As the result of an examination of the ground gone through in sinkings to the Barnsley coal in the neighbourhood of Doncaster, four further bands, all of which lie between the Shafton and the Barnsley coals, can now be added to the list, the positions of the same being approximately 700 feet, 575 feet, 385 feet, and 110 feet above the Barnsley coal.

The band about 700 feet above the Barnsley coal is the most important one of the four, and its distinctive characteristics make it an excellent datum line easy of recognition in the exploration of the concealed coalfield to the east of the county. It is 15 to 16½ feet thick. At the top it consists of blue shales marked with fucoids and having a soapy feeling to the touch. Similar shales below these are crowded with *Lingula mytiloides*. Beneath these are greyish-blue hard shales, which in turn rest on a hard greyish-blue limestone. The lower shales are very fossiliferous, and the limestone moderately so. The fossils obtained include five species of brachiopods, sixteen species of lamellibranchs, three species of gasteropods, thirteen species of cephalopods, and a crustacean. Among the fish remains is *Listracanthus wardi*.

Marine fossils have also been recently found in clay pits at Darfield, at Walton, near Wakefield, at Nostell, and at Castleford, but the position of the beds containing them in the geological sequence has not yet been fully worked out.

4. *The Occurrence of Marine Bands at Maltby.* *By* Wm. H. Dyson.

During the sinking operations at Maltby the writer has located the stratigraphical position of the fossils found, and has inspected the excavated débris day by day. Although all fossils have been collected, reference is only here made to the marine bands.

Taking the top of the Barnsley Coal (2,452 feet 2 inches deep or 2,193 feet 5 inches below Ordnance datum) as a base line, the lowest marine band, 8 feet 7 inches thick, occurred 340 feet 1 inch above the Barnsley Coal, the section being 1 foot 11 inches of bastard cannel overlain by 6 feet 8 inches of blackish bind with balls of pyrites, and contained the following fossils, mostly preserved in pyrites: *Lingula mytiloides*, ? *Posidoniella*, *Pterinopecten carbonarius*, *P. papyraceus*, *Scaldia carbonaria*, *Euphemus urei*, *Macrocheilina* sp., *Glyphioceras* sp., *Cœlacanthus*, ? *Cheirodus*, *Megalichthys*, *Rhadinichthys*

monensis, *Rhizodopsis sauroides*. Among these *Macrocheilina* was fairly abundant.

The next bed occurred 564 feet 1 inch above the Barnsley Coal. The material was dark-blue bind with ironstone and small cank-balls, and the following forms were present: *Lingula mytiloides*, *Orbiculoidea nitida*, *Myalina compressa*, *Straparollus* sp., *Euphemus urei*, *Naticopsis* sp., *Pleuronautilus costatus*, *Solenocheilus*, *cyclostoma*, *Acanthodes*, *Cladodus*, *Cœlacanthus*, *Megolichthys*, *Platysomus*, *Elonichthys* or *Acrolepis*, *Rhizodopsis*. Among these *Straparollus* is new to the Middle Coal Measures.

The next marine band, 20 feet ½ inch thick, lies 708 feet 10½ inches above the Barnsley Coal, the section being 19 feet ½ inch of dark greyish-blue shale with hard cank-balls, resting on 12 inches of argillaceous limestone. It contains an abundant fauna, including twenty-six genera and thirty-five species of invertebrates, all marine forms. *Chonetes laguessiana*, *Lingula mytiloides*, *Orbiculoidea nitida*, *Productus anthrax*, *Ctenodonta lævirostris*, *Myalina compressa*, *Nucula æqualis*, *N. gibbosa*, *N. luciniformis*, *Nuculana acuta*, *Posidoniella lævis*, *P. sulcata*, *Pseudamusium anisotum*, *P. fibrillosum*, *Pterinopecten papyraceus*, *Scaldia carbonaria*, *Schizodus antiquus*, *Syncyclonema carboniferum*, *Euphemus d'orbignyi*, *E. urei*, *Loxonema acutum*, *L. ashtonense*, *L.* sp., *Rhaphistoma radians*, *Bellerophon* sp., ? *Dimorphoceras gilbertsoni*, *Ephippioceras clittellarium*, *Gastrioceras carbonarium*, (?) *Glyphioceras paucilobum*, *G. phillipsi*, *G. reticulatum*, *G.* sp., *Orthoceras asciculare*, *O. sulcatum*=*Koninckianum*, *O.* sp., *Pleuronautilus costatus*, *Acanthodes*, *Cœlacanthus*, *Elonichthys*, *Listracanthus*, *Megalichthys*, *Platysomus*, *Rhizodopsis sauroides*. Among these *Pseudamusium anisotum* has not hitherto been found above the Carboniferous Limestone. Among the fish-remains *Listracanthus* should be noted.

The highest bed occurs 1,000 feet below the summit of the Middle Coal Measures, and 1,244½ feet above the Barnsley Coal. It is 10 feet 11 inches thick, consisting of grey bind with ironstone bands, of greasy appearance. The fauna is poor, but goniatites are not uncommon. *Lingula mytiloides*, *Orbiculoidea nitida*, *Myalina compressa*, *Nuculana acuta*, ? *Bellerophon* sp., *Glyphioceras phillipsi*, *G.* sp., *Orthoceras* sp., *Listracanthus*, *Megalichthys*, *Rhadinichthys monensis*. Among the fish-remains *Listracanthus* is to be recorded.

The writer is indebted to Dr. Wheelton Hind, F.G.S., and Dr. A. Smith Woodward, F.R.S., for examining and naming the fossils.

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5. *The Geology of the Titterstone Clee Hills.* *By* E. E. L. DIXON, *B.Sc., A.R.C.S., F.G.S.*

The following is a preliminary account of the rocks overlying the Lower Old Red Sandstone of the Titterstone Clee Hills, Shropshire:—

Sedimentary Series . . .	4. Coal-Measures.
	3. Millstone Grit (so-called).
	2. Carboniferous Limestone Series.
	1. Upper Old Red Sandstone.
Intrusive rocks	Dolerite.

(1) The Upper Old Red Sandstone, consisting largely of sandy and pebbly beds, is fixed in age by its fish-fauna, which has long been known. Its junction with the underlying Lower Old Red marls is perfectly sharp and probably marks an unconformity. Upward, however, the group passes into

(2) The Carboniferous Limestone Series. The correlation of the local development with the Avonian of other districts has been sketched by Dr. Vaughan,[1] whose chief conclusion, that the highest recognisable horizon is little, if at all, higher than the upper part of the Zaphrentis Zone, holds good throughout the outcrops. The part of the series which overlies this horizon is so thin that it is difficult to believe that the top is much younger, even after making allowance for the fact that it consists of such shallow-water deposits that its rate of deposition must have been conditioned by the rate of subsidence of the sea-

[1] *Quart. Journ. Geol. Soc.*, vol. lxi., 1905, pp. 252—4.

bottom. This conclusion as to age is supported by the age and relations to the local 'Millstone Grit,' of the top of the Carboniferous Limestone Series in the Forest of Dean and the Bristol area (*op. cit.*).

(3) The 'Millstone Grit,' which consists largely of sandstones and conglomerates, is undoubtedly conformable with the Carboniferous Limestone Series, and, as regards its base, is probably, from what has just been said, of Syringothyris age, and therefore much older than the Millstone Grit proper. Unfortunately its marine fossils, found at but one horizon, are of no zonal value, but its plants, from various levels, connect it, according to Dr. Kidston, with Lower Carboniferous rocks, not with the Millstone Grit proper. The conclusion that the lower part is older than the Millstone Grit proper may therefore extend to the whole, and it is suggested that a non-committal place-name be applied to this formation instead of 'Millstone Grit.'

(4) The Coal Measures include 'sweet,' *i.e.*, non-sulphurous, coals at several horizons from the base upward, and have yielded, besides a fairly rich flora, a small marine fauna at one or two horizons. The most important point, however, is the fact that they are not conformable with the 'Millstone Grit.' This relationship has been revealed in a quarry, where their basal bed, a pebbly sandstone, rests at a low inclination and with marked discordance on evenly-dipping beds of Grit; and it affords the only satisfactory explanation of a transgression of the Measures across the outcrops of the Grits, which is brought out by six-inch mapping.

As the 'Millstone Grit' is, in part at least, much older than the rocks of that name which underlie Coal Measures elsewhere, it becomes of interest to inquire whether the break between it and the Coal Measures on Clee Hill corresponds merely to the period of the Millstone Grit proper, or whether it includes some part of Coal Measure time also. That is, what is the age of the base of the Coal Measures on Clee Hill?

A feature of these measures is the presence in them of red clays and green sandstones of 'espley' type, at intervals from a few feet above the base upward. According to Dr. Walcot Gibson rocks of these characters are not known in Coal Measures of other parts of England and Wales from any horizon lower than the Etruria Marls or a short distance below. Stratigraphical evidence, also, suggests that the Coal Measures of Clee Hill commence at this level. For there is no doubt, as has been pointed out by Mr. Daniel Jones, but that the Clee Hill measures are on the same horizon as the 'sweet coal series' of the adjacent Forest of Wyre coalfield. There, in the Kinlet district, the junction of this series with the overlying sandstones which yield the 'sulphur coals' was found, in the course of an extension of the work to that neighbourhood, to be probably conformable; and therefore, as the sandstones have been recognised by Dr. Gibson and Mr. T. C. Cantrill as representing the Newcastle-under-Lyme Series, we may conclude that the 'sweet-coal series' which, like the Clee Hill measures, includes some red clays and 'espley'-like sandstones, corresponds to part of the Etruria Marls. It may be added that the most recent Coal Measures on Clee Hill are sandstones resembling the Newcastle Series of the Forest of Wyre, but too thin (they form an outlier of a few acres extent) and poorly exposed to yield further evidence of their age and relationships.

Against the conclusion that the Clee Hill measures commence with a representative of the Etruria Marls it may be urged that the latter in their typical development[1] yield neither coal-seams nor the flora and fauna which have been obtained on Clee Hill. Similar coals, however, occur elsewhere in England and Wales at intervals up to much higher horizons, though not in association with the typical Etruria Marl rock-facies. The objection based on the flora is of greater weight, for Dr. Kidston finds that the plants are Middle Coal Measure forms, and therefore suggestive of a horizon lower than the Etruria Marls. But it may be remarked that the flora of the Blackband Group immediately below the Etruria Marls—the latter yield but rare plants—includes no forms which do not occur in the Middle Coal Measures below.[2] The fauna of the marine bands is unfortunately of no horizonal value, though it includes a Productus which

[1] See Dr. Gibson, *Quart. Journ. Geol. Soc.*, vol. lvii., 1901, pp. 251 *et seq.*
[2] Dr. R. Kidston, *Quart. Journ. Geol. Soc.*, vol. lxi., 1905, p. 318.

Dr. Vaughan finds closely resembles a form (*P.* aff. *scabriculus*, Mart.) abundant in the Avon section and elsewhere at the top of the Dibunophyllum Zone.

Finally, a consideration of the thicknesses and characters of the sedimentary series and of the outcrops of dolerite shows that earth movements along a N.E.-S.W. line have made themselves felt during—

(1) Upper Old Red Sandstone and Lower Carboniferous times; and
(2) Some period between Lower Carboniferous and Coal Measure times. (This movement has resulted in the unconformity between the 'Millstone Grit' and the Coal Measures.)

And further that the dolerite came up through several passages, some of which form a linear series having approximately the same trend.

6. *Structural Petrifactions from the Mesozoic, and their bearing on Fossil Plant Impressions.* *By* Miss M. C. Stopes, *D.Sc., Ph.D., F.L.S.*

This paper dealt with the importance of the structural petrifactions in the Carboniferous—*e.g.*, exposure of the true nature of so many supposed 'ferns'; with the need of similar petrifactions from beds of Mesozoic age; and the danger of inferences drawn from plant *impressions*—*e.g.*, untrustworthiness of many of Heer's and Ettingshausen's systematic determinations.

The discovery of true petrifactions in the Cretaceous, the nature of the flora contained in the nodules, and unusual points in its composition were considered. Special illustrations of its interest are: *Yezonia*, a new type of which the external appearance gives no clue to its nature; the discovery of the first-known flower with its anatomy petrified; and of the internal anatomy of the leaves of *Nilssonia*, long well known as impressions.

7. *On some Rare Fossils from the Derbyshire and Nottinghamshire Coalfield.* *By* L. Moysey, *B.A., M.B., B.C., F.G.S.*

In the temporary museum in connection with this section there will be found a collection of fossils illustrating some of the rarer forms of the Coal Measure fauna obtained during the last eight years from this district. From these it has been thought desirable to select some, mainly fragmentary specimens, for more detailed description, in the hope that they may be of assistance in the identification of other more perfect specimens, should such be obtained, and that a discussion on their more perplexing features may lead to a more definite idea as to their affinities.

Specimen 1, from Shipley, near Ilkeston, Derbyshire.—These minute bodies, about 3 mm. long, are evidently the valves of the carapace of a phyllopod. A similar fossil was described by Lea[1] from Pennsylvania under the name of *Cypricardia leidyi*. Dr. T. Rupert Jones[2] gave it the name of *Leaia leidyi*, and described two varieties, one *L. leidyi* var. *Williamsoniana*, from Ardwick, near Manchester, and the other *L. leidyi* var. *Salteriana*, from Cottage Row, Crail, Fifeshire. The present example agrees fairly closely with the Fifeshire specimen; but, on the whole, it seems best to create a new species for it, *Leaia trigonoides* sp. nov., rather than risk confusion by adding a varietal appellation.

Specimen 2, from Shipley, is of interest, owing to the great difficulty of its interpretation. Possibly the best explanation is that it is the glabellar region of a Prestwichia. The presence of two minute crescentic dots, one on each side of the median line, is in favour of this theory, on the assumption that they are the larval eyes of the animal. Dr. Henry Woodward, however, who has examined this specimen, is very doubtful as to its lemuloid origin.

Specimen 3, from the Kilburn Coal, Trowell Colliery, Notts.—This has also been seen by Dr. Henry Woodward, who thinks it may be the terminal segments of a macrourous decapod, and may be allied to Pygocephalus. The curious feature in this specimen is the presence of crescentic openings on each segment

[1] *Proc. Acad. Nat. Sc. Philadelphia*, 1855, vii., p. 341, pl. 4.
[2] *Mon. Pal. Soc.*, 1862, Appendix, p. 115, Plate I., fig. 21, &c.

similar to the 'stigmata' found in scorpions and other arachnids, suggesting that it may be a fragment of an air-breathing animal.

Specimen 4, from Shipley, is probably one of the first abdominal segments of Eoscorpius sp., two specimens of which genus have been found in this district—one, described by Professor Huxley,[1] from near Chesterfield, and another, at present undescribed, found by the author in the Digby Claypit, Kimberley, Nottinghamshire.

Specimen 5, from Brindsley, Nottinghamshire, is a single segment of an arthropod, and possibly belongs to an Eurypterus.

Specimen 6, from Shipley, is the wing of an insect probably belonging to the order Palæodictyoptera of Scudder.

Specimens 7 and 8, also from Shipley, are a fragment of a much smaller insect's wing, which, in its incomplete state, would be impossible to assign to any definite order.

Insects' wings are very uncommon in the Coal Measures of this district, only one having been found near Chesterfield, and described by S. H. Scudder [2] under the name of *Archæoptilus ingens.*

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8. *The Origin of the British Trias. By* A. R. Horwood.

As a result of an investigation covering the Midland area, and especially from a study of the Upper Keuper of Leicestershire, the author, who has been aided in this research by a grant from the Government Grant Committee of the Royal Society, has arrived at the conclusion that, in so far as Great Britain is concerned, the Trias was laid down under delta conditions, during which, as in the Nile area to-day, æolian action took place, but was not responsible for deposition except locally on a small scale, and following the prevalent wind course.

The premisses upon which this view is based are as follows:—

1. There is a continuity of area of deposition during the Upper Carboniferous, Permian, and Triassic periods, and a relative homology between the different parts of each—*i.e.*, the base of each is similarly coarser than the top, and each has a red phase ultimately.

2. There is a gradual gradation from coarse sediments to finer from below upwards, as in modern (and other fossil) deltas. For instance, pebbles predominate in the lower phase, coarse sandstones (with occasional pebbles) in the centre, and finer and finer marls succeed in the last phase, which becomes increasingly ferruginous, as it merges into the lake-phase of the delta period.

3. The oldest member of the series, the Bunter, is acknowledged to be a delta-formation—as Professor Bonney showed many years ago—and there is no evidence for the discontinuity of the agency producing that mode of deposition.

4. The continuity of the Bunter and Keuper is an argument for the extension of delta conditions to the Keuper, some 'basement beds' being indistinguishable from the Bunter.

5. The general evidence of an oscillation of level in early Triassic times and of overlapping is a proof of aqueous agency. Coupled together these vertical and horizontal movements are more distinctive of fluviatile than lacustrine or marine conditions.

6. There is a close analogy between the contour or geographical configuration of the Trias (whether we consider concealed or exposed areas), and modern deltas—*e.g.*, the Mississippi, with its dactyloid extensions beyond the head.

7. There is a distinct analogy between the regular alternations of pebbles or sand and marl and seasons of torrential rains and floods or drought; that is to say, one sort of sediment is brought down at one period of the year, another at another. This may be witnessed in modern accumulations such as those of the Nile or Mississippi, where floods occur. These alternations are due to overflow of banks where 'skerries' lie on the hilly grounds now, just as they did when they were deposited. The grey marl is heavier than the red, and deposits are arranged as in a diffusion column.

1 Reference not determinable.

2 S. H. Scudder, 'Haxapod Insects of Great Britain,' *Mem. Boston Nat. Hist. Soc.*, vol. iii., pp. 217-218, 1873-1894.

8. The coloration of the Trias is original; that is to say, the red colour, imparted by peroxide of iron, was deposited on sediments under water-level. But it is not continuous everywhere with the bedding. 'Catenary' bedding is thus illusory. In only one case has an anticlinal fold of red-coloured marl been noticed underlying a grey band, but, on the other hand, synclinal folds are not uncommon, as in catenary bedding, the grey (heavier) marl lying in the hollows.

9. The great thickness of the Bunter pebble beds is a proof of a subsiding area at the opening of the Trias and of conditions suitable to a gradually widening and deeper delta area.

Normally delta deposits lie at an angle of about 45 degrees with the river bed, but as they are deposited in a subsiding area these beds describe an angle of 45 degrees and *become horizontal*. Thus the absence of delta bedding (not everywhere, for it occurs in Bunter, Lower and Upper Keuper here and there) in the Trias is proof that it was deposited in a subsiding area.

The 'radial dip' around submerged areas is due to the 'angle of rest' which normally produces inclined beds. The winding of the course of a river like the Mississippi, producing wide alluvial plains, would account for the Red Marl being deposited much as in a lacustrine area.

10. There is evidence from analogy of the ferruginous nature of the Upper Coal Measures, Permian, and Trias of the delta origin of the red marls.

11. The present horizontality, the littoral or marginal dip around the hills (*e.g.*, Charnwood Forest), with the south-easterly dip (as in the Coal Measures and Permian formation), is original.

Trias reaches a height of 880 feet on Bardon Hill and is apparently *in situ*. Hence the elevated tracts must originally have been under water.

Moreover, the following facts may be noted in connection with submerged hills under the Triassic covering:—

(i) The Trias is horizontal away from the older hills, as at Hathern, Sileby, &c.

(ii) It is horizontal within old gullies and fiords within the islandic area as well as over 'saddlebacks' (anticlinal folds in older rocks, as at Longcliffe, Enderby), as at Groby, Swithland, Mount Sorrel.

(iii) There is an absence of faults of any magnitude. A very slight one affects the Rhætics at Glen Parva. The older one at Bardon has no relation to the Trias.

(iv) It occurs filling fissures at great heights, as at Siberia Quarry, Bardon Hill.

12. Only the sandstones or 'skerries' are rippled, not the marls, with ripples S.W. to N.E. in direction; that is, the ridges run N.W. by S.E. generally, the force moving the wind and wave thus coming from the S.W. This is to be noted all round Charnwood Forest.

13. The screes are very largely to the S.W. of the submerged older rocks which they cover, and from which (as on sea-coasts dunes are formed with screes forming at the foot of cliffs) they are derived.

14. The sandstones thin out and disappear eastward (as in the Lower Keuper), the marls westward, and the sandstones or skerries are chiefly on present hilly ground (as in the past).

15. The surface features of the old elevated rocks are largely original, where not covered by the Trias. The crags of High Sharpley, Broombriggs, &c., are quite untouched. The structure of the older formation can be distinctly made out as at Hanging Rocks. Blackbrook is only an emptied Triassic fiord.

16. Desert conditions are confined to the marginal contact of the Red Marl with certain older rocks (chiefly syenites as at Croft and Mount Sorrel), and this occurs at the same level indicating its merely local phase. Wind-polished rocks occur to the west and north of Castle Hill, Mount Sorrel.

17. There is an absence of desert conditions in the surrounding area—*i.e.*, away from the old rocks. Only in one instance has an anticlinal fold of Red Marl, simulating a dune been discovered, as at Sileby.

18. The beds of gypsum and rock-salt are continuous in a linear direction, and are horizontal, which must be due to aqueous deposition, and brought about during the greater lagoon phase at the close of the epoch, or the contemporary marginal lagoon phase during early periods of the delta formation.

19. There is a gradual gradation of the Keuper into the Rhætics and so into the Lias, marine conditions commencing with the Rhætics.

20. The source of the sediments is in a large measure correlated with that of the Bunter, which was formed by a river coming from north-west Scotland.

21. There is a correspondence between the characteristics of the micropetrography of the Bunter, Keuper, and modern delta formations. The Leicestershire Trias shows signs of chemical action, the Nile delta of mechanical. The chemical composition of volcanic and metamorphic rocks locally argues a local as well as a distant source for the heavier minerals of the Keuper.

22. The evidence of the flora and fauna shows that there were provinces, and these were so arranged as to allow for the prevalence of delta conditions. The climate was moist and equable.

Finally, we conclude that there is nothing to prove that desert conditions did anything more than locally act upon the rocks mechanically, and to some extent chemically. *They had no part whatever in the work of deposition;* that is to say, they disintegrated the previous rocks (pre-Triassic). There is positive, direct, and accumulative evidence to prove that the Trias as a whole (and not the Bunter only) was the work of rivers which have continued to bring sediment in one form or another from the north-west of Britain or the north more or less continuously, under one condition or another, from the close of the marine phase of Lower Carboniferous (Mountain Limestone) times.

9. *On a Buried Tertiary Valley through the Mercian Chalk Range and its later 'Rubble Drift.'* *By* Rev. A. Irving, *D.Sc., B.A.*

The author referred to his paper read at the Cambridge Meeting (1904), to the previous papers therein referred to, and to the report of an excursion in 1905.[1] New evidence was brought forward showing the actual trend of the buried tertiary valley through the Chalk Range; also evidence bearing upon the later glaciation, and the post-glacial physiography of the upper Stort Valley, especially dealing with the 'rubble drift,' which frequently mantles the upper slopes of the valley and admits of a true correlation with the series described by Prestwich.[2] This includes (1) sections furnished by some 300 graves in Hockerill churchyard; (2) interglacial sands with boulders covered by a later boulder clay; (3) remains of *Elephas primigenius* found in the rubble drift; (4) remains of horse (on both sides of the valley), of red deer (at Stortford and Sawbridgeworth), of *Bos* (in considerable quantity at both those places); (5) teeth of horse and *Bos*; (6) a perforated fragment of antler of red deer; (7) a core of horn of aurochs attached to skull fragment; (8) oysters, grypheas, and belemnites from the boulder clay. With these occur human artefacts—Palæolithic and Neolithic flint implements and 'cores,' fragments of baking-tiles, fragments of pottery (Neolithic and Bronze periods), primitive bricks (moulded with human hands), an ingot of crude bronze, fragments of charcoal, and a variety of boulders.

Especial attention was directed to the *work of high-level springs* fed by the more sandy and gravelly portions of the glacial drift of the hill-cap. Since the retreat of the ice the most powerful of these springs has been cutting back into the London Clay, and the consequent lateral landslides formerly ponded back the water, producing a bog, recently laid open in the excavation of a pond, and found to contain a *Holocene molluscan fauna.* In that bog the *horse-skeleton*[3] was found, coated with a black carbonised deposit, buried beneath the clay of the later landslides of the hill, along with the vegetable contents of the paunch reduced to the state of peat. The London Clay behind this mantle of 'rubble drift' and the glacial cap of the hill[4] have been proved by four borings made into the cap and shoulder of the hill. The assemblage of geological features here bears comparison with those at Schussenried described by Oscar Fraas,[5] and the bones (in one place mixed with fragments of tiles suggesting a prehistoric 'refuse-heap') are in much the same stage of decay as those described by Naumann from the pile-dwelling site of Starnberger See.[6] An interesting lithological observation of *glauconite* formed in grains on flints is recorded.

[1] *P. G. A.*, vol. xix.

[2] *Q. J. G. S.*, vol. xlviii., May 1892.

[3] See *Ill. Lon. News*, June 5, 1909.

[4] *Mem. Geol. Survey*, vol. iv., p. 449.

[5] *Arch. f. Anthrop.*, 2nd Bd., 1867.

[6] *Ibid.*, 8th Bd., 1875.

WEDNESDAY, SEPTEMBER 7.

The following Papers and Reports were read :—

1. *The Pre-Oceanic Stage of Planetary Development, and its Bearing on Earliest History of the Lithosphere and the Hydrosphere.* By Rev. A. IRVING, *D.Sc., B.A.*

The phrase 'pre-oceanic stage,' as used by the author[1] for more than twenty years, is explained, and it is thought that the present offers an opportunity for a fuller discussion of what is connoted by it, since it appears to have been generally ignored by geologists as if connoting something ultra-geological. The physical principles involved are briefly stated, and special reference is made to the author's letter in 'Nature'[2] five years ago. The bearing of the idea upon the results established in recent years for the pre-Cambrian series of rocks, as set forth by Professor W. G. Müller[3] last year at Winnipeg, and by Van Hise[4] two years ago, is discussed, all tending to throw light upon the true position, in the lithospheric succession, of the great crystalline-schist series, as advocated by the author in 1888-89, and by Lawson[5] in 1890, on the lines intimated by Bonney[6] and Credner.[7] Reference is made to the mineral origin of graphite in the Archæan stage,[8] and the probable derivative origin of that found in the Algonkian (Huronian) slates, &c. The great unconformities and basal conglomerates in the North American series and in other areas are referred to the abrading and erosive and abrasive action of the tides upon the early submarine crustal elevations, when the moon was nearer to the earth than at present,[9] while in other areas there is an unbroken succession. Criticisms are offered upon a certain theory in vogue as to the salinity of ocean waters and upon certain recent pronouncements of Professor T. C. Chamberlin.[10] Reference is made to 'spiral nebulæ,' as illustrating the idea of the nucleate origin of the planets of the solar system suggested by the author in 1889[11] and advocated by him more recently.[12]

2. *Report on the Erratic Blocks of the British Isles.*—See Reports, p. 100.

3. *Fifth Report on the Crystalline Rocks of Anglesey.*—See Reports, p. 110.

4. *Report on the Faunal Succession in the Lower Carboniferous Limestone (Avonian) of the British Isles.*—See Reports, p. 106.

5. *Report on the Excavation of Critical Sections in the Palæozoic Rocks of Wales and the West of England.*—See Reports, p. 113.

[1] A. Irving, *Metamorphism of Rocks* (Longmans, 1889); also on 'The Malvern Crystallines,' *Geol. Mag.*, October 1902.

[2] 'On the Consolidation of the Earth,' *Nature*, May 25, 1905.

[3] *Brit. Assoc. Report*, 1909.

[4] Presidential Address to the Geol. Soc. of America, 1908.

[5] *Bulletin Geol. Soc. of America*, vol. i., pp. 175–194.

[6] Presidential Address to the Geol. Soc. of London, 1886.

[7] *Geologie* (Leipzig, 10th ed., 1906).

[8] A. Irving, *Brit. Assoc. Report*, 1888, pp. 630, 679 (Bath Meeting); *Chemical News*, No. 1505; *Met. of Rocks*, pp. 116–119.

[9] A. Irving, *op. cit.*, p. 91 (reading now pre-Cambrian for 'Cambrian').

[10] *Nature*, March 10, 1910.

[11] A. Irving, *op. cit.*, p. 22. Also Appendix ii., note c.

[12] *Trans. Vic. Institute*, vol. xxxviii., pp. 79, 80; also vol. xlii., pp. 187, 220.

6. *Interim Report on the Microscopical and Chemical Composition of Charnwood Rocks.*

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7. *Report on the Igneous and Associated Rocks of the Glensaul and Lough Nafooey Areas, Cos. Mayo and Galway.*—See Reports, p. 110.

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8. *Report on the Correlation and Age of South African Strata, &c.* See Reports, p. 123.

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9. *Report of the Geological Photographs Committee.* See Reports, p. 142.

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10. *Report on the Fossil Flora and Fauna of the Midland Coalfields.* See Appendix, p. 827.

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11. *Report on Topographical and Geological Terms used locally in South Africa.*—See Reports, p. 160.

SECTION D.—ZOOLOGY.

PRESIDENT OF THE SECTION.—Professor G. C. BOURNE, M.A., D.Sc., F.R.S.

THURSDAY, SEPTEMBER 1.

The President delivered the following Address :—

IN choosing a subject for the address with which it is my duty, as President of this Section, to trouble you, I have found myself in no small embarrassment. As one whose business it is to lecture and give instruction in the details of comparative anatomy, and whose published work, *qualecunque sit*, has been indited on typical and, as men would now say, old-fashioned morphological lines, I seem to stand self-condemned as a morphologist. For morphology, if I read the signs of the times aright, is no longer in favour in this country, and among a section of the zoological world has almost fallen into disgrace. At all events, I have been very frankly assured that this is the case by a large proportion of the young gentlemen whom it has been my fate to examine during the past two years; and, as this seems to be the opinion of the rising generation of English zoologists, and as there are evident signs that their opinion is backed by an influential section of their elders, I have thought that it might be of some interest, and perhaps of some use, if I took this opportunity of offering an apology for animal morphology.

It is a sound rule to begin with a definition of terms, so I will first try to give a short answer to the question 'What is morphology?' and, when I have given a somewhat dogmatic answer, I will try to deal in the course of this address with two further questions : What has morphology done for zoological science in the past? What remains for morphology to do in the future?

To begin with, then, what do we include under the term morphology? I must, first of all, protest against the frequent assumption that we are bound by the definitions of C. F. Wolff or Goethe, or even of Haeckel, and that we may not enlarge the limits of morphological study beyond those laid down by the fathers of this branch of our science. We are not—at all events we should not be—bound by authority, and we owe no allegiance other than what reason commends to causes and principles enunciated by our predecessors, however eminent they may have been.

The term morphology, stripped of al the theoretical conceptions that have clustered around it, means nothing more than the study of form, and it is applicable to all branches of zoology in which the relationships of animals are determined by reference to their form and structure. Morphology, therefore, extends its sway not only over the comparative anatomy of adult and recent animals, but also over palæontology, comparative embryology, systematic zoology and cytology, for all these branches of our science are occupied with the study of form. And in treating of form they have all, since the acceptance of the doctrine of descent with modification, made use of the same guiding principle—namely, that likeness of form is the index to blood-relationship. It was the introduction of this principle that revolutionised the methods of morphology fifty years ago, and stimulated that vast output of morphological work which some persons, erroneously as I think, regard as a departure from the line of progress indicated by Darwin.

We may now ask, what has morphology done for the advancement of zoological science since the publication of the 'Origin of Species'? We need not stop to inquire what facts it has accumulated : it is sufficiently obvious that it has added enormously to our stock of concrete knowledge. We have rather to ask what great general principles has it established on so secure a basis that they meet with universal acceptance at the hands of competent zoologists?

It has doubtless been the object of morphology during the past half-century to illustrate and confirm the Darwinian theory. How far has it been successful?

To answer this question we have to be sure of what we mean when we speak of the Darwinian theory. I think that we mean at least two things. (1) That the assemblage of animal forms as we now see them, with all their diversities of form, habit, and structure, is directly descended from a precedent and somewhat different assemblage, and these in turn from a precedent and more different assemblage, and so on down to remote periods of geological time. Further, that throughout all these periods inheritance combined with changeability of structure have been the factors operative in producing the differences between the successive assemblages. (2) That the modifications of form which this theory of evolution implies have been rejected or preserved and accumulated by the action of natural selection.

As regards the first of these propositions, I think there can be no doubt that morphology has done great service in establishing our belief on a secure basis. The transmutation of animal forms in past time cannot be proved directly; it can only be shown that, as a theory, it has a much higher degree of probability than any other that can be brought forward, and in order to establish the highest possible degree of probability, it was necessary to demonstrate that all anatomical, embryological, and palæontological facts were consistent with it. We are apt to forget, nowadays, that there is no *a priori* reason for regarding the resemblances and differences that we observe in organic forms as something different in kind from the analogous series of resemblances and differences that obtain in inanimate objects. This was clearly pointed out by Fleeming Jenkin in a very able and much-referred to article in the 'North British Review' for June 1867, and his argument from the *a priori* standpoint has as much force to-day as when it was written forty-three years ago. But it has lost almost all its force through the arguments *a posteriori* supplied by morphological science. Our belief in the transmutation of animal organisation in past time is founded very largely upon our minute and intimate knowledge of the manifold relations of structural form that obtain among adult animals; on our precise knowledge of the steps by which these adult relations are established during the development of different kinds of animals; on our constantly increasing knowledge of the succession of animal forms in past time; and, generally, on the conviction that all the diverse forms of tissues, organs, and entire animals are but the expression of an infinite number of variations of a single theme, that theme being cell-division, multiplication, and differentiation. This conviction grew but slowly in men's minds. It was opposed to the cherished beliefs of centuries, and morphology rendered a necessary service when it spent all those years which have been described as 'years in the wilderness' in accumulating such a mass of circumstantial evidence in favour of an evolutionary explanation of the order of animate nature as to place the doctrine of descent with modification on a secure foundation of fact. I do not believe that this foundation could have been so securely laid in any other way, and I hold that zoologists were actuated by a sound instinct in working so largely on morphological lines for forty years after Darwin wrote. For there was a large mass of fact and theory to be remodelled and brought into harmony with the new ideas, and a still larger vein of undiscovered fact to explore. The matter was difficult and the pace could not be forced. Morphology, therefore, deserves the credit of having done well in the past: the question remains, What can it do in the future?

It is evident, I think, that it cannot do much in the way of adding new truths and general principles to zoological science, nor even much more that is useful in the verification of established principles, without enlarging its scope and methods. Hitherto—or, at any rate, until very recently—it has accepted certain guiding principles on faith, and, without inquiring too closely into their validity, has occupied itself with showing that, on the assumption that these principles are true, the phenomena of animal structure, development, and succession receive a reasonable explanation.

We have seen that the fundamental principles relied upon during the last fifty years have been inheritance and variation. In every inference drawn from the comparison of one kind of animal structure with another, the morphologist founds himself on the assumption that different degrees of similitude correspond more or less closely to degrees of blood-relationship, and to-day there are probably few persons who doubt that this assumption is valid. But we must not forget that, before the publication of the 'Origin of Species,' it was rejected by the most influential zoologists as an idle speculation, and that it is imperilled by

Mendelian experiments showing that characters may be split up and reunited in different combinations in the course of a few generations. We do not doubt the importance of the principle of inheritance, but we are not quite so sure as we were that close resemblances are due to close kinship and remoter resemblances to remoter kinship.

The principle of variation asserts that like does not beget exactly like, but something more or less different. For a long time morphologists did not inquire too closely into the question how these differences arose. They simply accepted it as a fact that they occur, and that they are of sufficient frequency and magnitude, and that a sufficient proportion of them lead in such directions that natural selection can take advantage of them. Difficulties and objections were raised, but morphology on the whole took little heed of them. Remaining steadfast in its adherence to the principles laid down by Darwin, it contented itself with piling up circumstantial evidence, and met objection and criticism with an ingenious apologetic. In brief, its labours have consisted in bringing fresh instances, and especially such instances as seem unconformable, under the rules, and in perfecting a system of classification in illustration of the rules. It is obvious, however, that, although this kind of study is both useful and indispensable at a certain stage of scientific progress, it does not help us to form new rules, and fails altogether if the old rules are seriously called into question.

As a matter of fact, admitting that the old rules are valid, it has become increasingly evident that they are not sufficient. Until a few years ago morphologists were open to the reproach that, while they studied form in all its variety and detail, they occupied themselves too little—if, indeed, they could be said to occupy themselves at all—with the question of how form is produced, and how, when certain forms are established, they are caused to undergo change and give rise to fresh forms. As Klebs has pointed out, the forms of animals and plants were regarded as the expression of their inscrutable inner nature, and the stages passed through in the development of the individual were represented as the outcome of purely internal and hidden laws. This defect seems to have been more distinctly realised by botanical than by zoological morphologists, for Hofmeister, as long ago as 1868, wrote that the most pressing and immediate aim of the investigator was to discover to what extent external forces acting on the organism are of importance in determining its form.

If morphology was to be anything more than a descriptive science, if it was to progress any further in the discovery of the relations of cause and effect, it was clear that it must alter its methods and follow the course indicated by Hofmeister. And I submit that an inquiry into the causes which produce alteration of form is as much the province of, and is as fitly called, morphology as, let us say, a discussion of the significance of the patterns of the molar teeth of mammals or a disputation about the origin of the cœlomic cavities of vertebrated and invertebrated animals.

There remains, therefore, a large field for morphology to explore. Exploration has begun from several sides, and in some quarters has made substantial progress. It will be of interest to consider how much progress has been made along certain lines of research—we cannot now follow all the lines—and to forecast, if possible, the direction that this pioneer work will give to the morphology of the future.

I am not aware that morphologists have, until quite recently, had any very clear concept of what may be expected to underlie form and structure. Dealing, as they have dealt, almost exclusively with things that can be seen or rendered visible by the microscope, they have acquired the habit of thinking of the organism as made up of organs, the organs of tissues, the tissues of cells, and the cells as made up—of what? Of vital units of a lower order, as several very distinguished biologists would have us believe; of physiological units, of micellæ, of determinants and biophors, or of pangenes; all of them essentially morphological conceptions; the products of imagination projected beyond the confines of the visible, yet always restrained by having only one source of experience—namely, the visible. One may give unstinted admiration to the brilliancy, and even set a high value on the usefulness, of these attempts to give formal representations of the genesis of organic structure, and yet recognise that their chief utility has been to make us realise more clearly the problems that have yet to be solved.

Stripped of all the verbiage that has accumulated about them, the simple questions that lie immediately before us are : What are the causes which produce

changes in the forms of animals and plants? Are they purely internal, and, if so, are their laws discoverable? Or are they partly or wholly external, and, if so, how far can we find relations of cause and effect between ascertained chemical and physical phenomena and the structural responses of living beings?

As an attempt to answer the last of these questions, we have the recent researches of the experimental morphologists and embryologists directed towards the very aim that Hofmeister proposed. Originally founded by Roux, the school of experimental embryology has outgrown its infancy and has developed into a vigorous youth. It has produced some very remarkable results, which cannot fail to exercise a lasting influence on the course of zoological studies. We have learnt from it a number of positive facts, from which we may draw very important conclusions, subversive of some of the most cherished ideas of whilom morphologists. It has been proved by experiment that very small changes in the chemical and physical environment may and do produce specific form-changes in developing organisms, and in such experiments the consequence follows so regularly on the antecedent that we cannot doubt that we have true relations of cause and effect. It is not the least interesting outcome of these experiments that, as Loeb has remarked, it is as yet impossible to connect in a rational way the effects produced with the causes which produced them, and it is also impossible to define in a simple way the character of the change so produced. For example, there is no obvious connection between the minute quantity of sulphates present in sea-water and the number and position of the characteristic calcareous spicules in the larva of a sea-urchin. Yet Herbst has shown that if the eggs of sea-urchins are reared in sea-water deprived of the needful sulphates (normally 0·26 per cent. magnesium sulphate and ·1 per cent. calcium sulphate), the number and relative positions of these spicules are altered, and, in addition, changes are produced in other organs, such as the gut and the ciliated bands. Again, there is no obvious connection between the presence of a small excess of magnesium chloride in sea-water and the development of the paired optic vesicles. Yet Stockard, by adding magnesium chloride to sea-water in the proportion of 6 grams of the former to 100 c.c. of the latter, has produced specific effects on the eyes of developing embryos of the minnow *Fundulus heteroclitus*: the optic vesicles, instead of being formed as a widely separated pair, were caused to approach the median line, and in about 50 per cent. of the embryos experimented upon the changes were so profound as to give rise to cyclopean monsters. Many other instances might be cited of definite effects of physical and chemical agencies on particular organs, and we are now forced to admit that inherited tendencies may be completely overcome by a minimal change in the environment. The nature of the organism, therefore, is not all important, since it yields readily to influences which at one time we should have thought inadequate to produce perceptible changes in it.

It is open to anyone to argue that, interesting as experiments of this kind may be, they throw no light on the origin of permanent—that is to say, inheritable—modifications of structure. It has for a long time been a matter of common knowledge that individual plants and animals react to their environment, but the modifications induced by these reactions are somatic; the germ-plasm is not affected, therefore the changes are not inherited, and no permanent effect is produced in the characters of the race or species. It is true that no evidence has yet been produced to show that form-changes as profound as those that I have mentioned are transmitted to the offspring. So far the experimenters have not been able to rear the modified organisms beyond the larval stages, and so there are no offspring to show whether cyclopean eyes or modified forms of spicules are inherited or not. Indeed, it is possible that the balance of organisation of animals thus modified has been upset to such an extent that they are incapable of growing into adults and reproducing their kind.

But evidence is beginning to accumulate which shows that external conditions may produce changes in the germ-cells as well as in the soma, and that such changes may be specific and of the same kind as similarly produced somatic changes. Further, there is evidence that such germinal changes are inherited—and, indeed, we should expect them to be, because they are germinal.

The evidence on this subject is as yet meagre, but it is of good quality and comes from more than one source.

There are the well-known experiments of Weismann, Standfuss, Merrifield, and E. Fischer on the modification of the colour patterns on the wings of various Lepidoptera.

In the more northern forms of the fire-butterfly, *Chrysophanus* (*Polyommatus*) *phlœas*, the upper surfaces of the wings are of a bright red-gold or copper colour with a narrow black margin, but in southern Europe the black tends to extend over the whole surface of the wing and may nearly obliterate the red-gold colour. By exposing pupæ of caterpillars collected at Naples to a temperature of 10° C. Weismann obtained butterflies more golden than the Neapolitan, but blacker than the ordinary German race, and conversely, by exposing pupæ of the German variety to a temperature of about 38° C., butterflies were obtained blacker than the German, but not so black as the Neapolitan variety. Similar deviations from the normal standard have been obtained by like means in various species of Vanessa by Standfuss and Merrifield. Standfuss, working with the small tortoise-shell butterfly (*Vanessa urticæ*), produced colour aberrations by subjecting the pupæ to cold, and found that some specimens reared under normal conditions from the eggs produced by the aberrant forms exhibited the same aberrations, but in a lesser degree. Weismann obtained similar results with the same species. E. Fischer obtained parallel results with *Arctia caja*, a brightly coloured diurnal moth of the family Bombycidæ. Pupæ of this moth were exposed to a temperature of 8° C., and some of the butterflies that emerged were very dark-coloured aberrant forms. A pair of these dark aberrants were mated, and the female produced eggs, and from these larvæ and pupæ were reared at a normal temperature. The progeny was for the most part normal, but some few individuals exhibited the dark colour of the parents, though in a less degree. The simple conclusions to be drawn from the results of these experiments is that a proportion of the germ-cells of the animals experimented upon were affected by the abnormal temperatures, and that the reaction of the germ-cells was of the same kind as the reaction of the somatic cells and produced similar results. As everybody knows, Weismann, while admitting that the germ-cells were affected, would not admit the simple explanation, but gave another complicated and, in my opinion, wholly unsupported explanation of the phenomena.

In any case this series of experiments was on too small a scale, and the separate experiments were not sufficiently carefully planned to exclude the possibility of error. But no objection of this kind can be urged against the careful and prolonged studies of Tower on the evolution of chrysomelid beetles of the genus Leptinotarsa. *Leptinotarsa*—better known, perhaps, by the name *Doryphora*—is the potato-beetle, which has spread from a centre in North Mexico southwards into the isthmus of Panama and northwards over a great part of the United States. It is divisible into a large number of species, some of which are dominant and widely ranging; others are restricted to very small localities. The specific characters relied upon are chiefly referable to the colouration and colour patterns of the epicranium, pronotum, elytra, and underside of the abdominal segments. In some species the specific markings are very constant, in others, particularly in the common and wide-ranging *L. decemlineata*, they vary to an extreme degree. As the potato-beetle is easily reared and maintained in captivity, and produces two broods every year, it is a particularly favourable subject for experimental investigation. Tower's experiments have extended over a period of eleven years, and he has made a thorough study of the geographical distribution, dispersal, habits, and natural history of the genus. The whole work appears to have been carried out with the most scrupulous regard to scientific accuracy, and the author is unusually cautious in drawing conclusions and chary of offering hypothetical explanations of his results. I have been greatly impressed by the large scale on which the experiments have been conducted, by the methods used, by the care taken to verify every result obtained, and by the great theoretical importance of Tower's conclusions. I can do no more now than allude to some of the most remarkable of them.

After showing that there are good grounds for believing that colour production in insects is dependent on the action of a group of closely related enzymes, of which chitase, the agent which produces hardening of chitin, is the most important, Tower demonstrates by a series of well-planned experiments that colours are directly modified by the action of external agencies—viz., temperature, humidity, food, altitude, and light. Food chiefly affects the subhypodermal colours of the larvæ, and does not enter much into account; the most important agents affecting the adult colouration being temperature and humidity. A *slight* increase or a *slight* decrease of temperature or humidity was found to stimulate

the action of the colour-producing enzymes, giving a tendency to melanism; but a large increase or decrease of temperature or humidity was found to inhibit the action of the enzymes, producing a strong tendency to albinism.

A set of experiments was undertaken to test the question whether coloration changes induced by changed environmental conditions were inherited, increased, or dropped in successive generations. These experiments, carried on for ten lineal generations, showed that the changed conditions immediately produced their maximum effect; that they were purely somatic and were not inherited, the progeny of individuals which had been exposed to changed conditions through several generations promptly reverting when returned to normal conditions of environment. So far the results are confirmatory of the well-established proposition that induced somatic changes are not inheritable.

But it was found necessary to remove the individuals experimented upon from the influence of changed conditions during the periods of growth and maturation of the germ-cells. Potato-beetles emerge from the pupa or from hibernation with the germ-cells in an undeveloped condition, and the ova do not all undergo their development at once, but are matured in batches. The first batch matures during the first few days following emergence, then follows an interval of from four to ten days, after which the next batch of eggs is matured, and so on. This fact made it possible to test the effect of altered conditions on the maturing germ-cells by subjecting its imagos to experimental conditions during the development of some of the batches of ova and to normal conditions during the development of other batches.

In one of the experiments four male and four female individuals of *L. decemlineata* were subjected to very hot and dry conditions, accompanied by low atmospheric pressure, during the development and fertilisation of the first three batches of eggs. Such conditions had been found productive of albinic deviations in previous experiments. As soon as the eggs were laid they were removed to normal conditions, and the larvæ and pupæ reared from them were kept in normal conditions. Ninety-eight adult beetles were reared from these batches of eggs, of which eighty-two exhibited the characters of an albinic variety found in nature and described as a species under the name *pallida;* two exhibited the characters of another albinic species named *immaculothorax*, and fourteen were unmodified *decemlineatas*. This gave a clear indication that the altered conditions had produced modifications in the germ-cells which were expressed by colour changes in the adult individuals reared from them. To prove that the deviations were not inherent in the germ-plasm of the parents, the latter were kept under normal conditions during the periods of development and fertilisation of the last two batches of eggs; the larvæ and pupæ reared from these eggs were similarly subjected to normal conditions, and gave rise to sixty-one unmodified *decemlineatas*, which, when bred together, came true to type for three generations. The *decemlineata* forms produced under experimental conditions also came true to type when bred together. Of the *pallida* forms produced by experimental conditions all but two males were killed by a bacterial disease. These two were crossed with normal *decemlineata* females, and the result was a typical Mendelian segregation, as shown by the followng table:—

2 ♂ pallida × 2 ♀ decemlineata

↓

Hybrids, decemlineata characters dominant

5 ♂ × 3 ♀

Pallida 6 ♂, 4 ♀		Decemlineata and hybrids 16 ♂, 14 ♀
↓	↙	↘
Pallida 18 ♂, 23 ♀	Pallida 8 ♂, 7 ♀	Decemlineata and hybrids 26 ♂, 28 ♀

This is a much more detailed experiment than those of Standfuss, Merrifield, and Fisher, and it shows that the changes produced by the action of altered conditions on the maturing germ-cells were definite and discontinuous, and therefore of the nature of mutations in De Vries' sense.

In another experiment Tower reared three generations of *decemlineata* to test the purity of his stock. He found that they showed no tendency to produce extreme variations under normal conditions. From this pure stock seven males and seven females were chosen and subjected during the maturation periods of the first two batches of ova to hot and dry conditions. Four hundred and nine eggs were laid, from which sixty-nine adults were reared, constituted as follows :

Twenty (12 ♂, 8 ♀) . . .	apparently normal *decemlineata*.
Twenty-three (10 ♂, 13 ♀) .	*pallida*.
Five (2 ♂, 3 ♀)	*immaculothorax*.
Sixteen (9 ♂, 7 ♀)	*albida*.

These constituted lot A.

The same seven pairs of parents subjected during the second half of the reproductive period to normal conditions gave 840 eggs, from which were reared 123 adults, all *decemlineatas*. These constituted lot B. The *decemlineatas* of lot A and lot B were reared side by side under normal and exactly similar conditions. The results were striking. From lot B normal progeny were reared up to the tenth generation, and, as usual in the genus, two generations were produced in each year. The *decemlineatas* of lot A segregated into two lots in the second generation. A^1 were normal in all respects, but A^2, while retaining the normal appearance of *decemlineata*, went through five generations in a year, and this for three successive years, thus exhibiting a remarkable physiological modification, and one without parallel in nature, for no species of the genus *Leptinotarsa* are known which produce more than two generations in the year. This experiment is a sufficient refutation of Weismann's argument that the inheritance of induced modifications in *Vanessa urticæ* is only apparent, the phenomena observed being due to the inheritance of two kinds of determinants—one from dark-coloured forms which are phyletically the oldest, and the other from more gaily coloured forms derived from the darker forms. There is no evidence whatever that there was ever a species or variety of potato-beetle that produced more than two, or at the most, and then as an exception, three broods in a year.

The modified albinic forms in this last experiment of Tower's were weakly; they were bred through two or three generations and came true to type, but then died out. No hybridisation experiments were made with them but in other similar experiments, which I have not time to mention in detail, modified forms produced by the action of changed conditions gave typical Mendelian characters when crossed with unmodified *decemlineatas*, thus proving that the induced characters were constant and heritable according to the regular laws.

I have thought it worth while to relate these experiments at some length, because they seem to me to be very important, and because they do not appear to have attracted the attention in this country that they deserve.

They are confirmed to a very large extent by the experiments of Professor Klebs on plants, the results of which were published this summer in the Croonian Lecture on 'Alterations of the Development and Forms of Plants as a Result of Environment.' As I have only a short abstract of the Croonian Lecture to refer to, I cannot say much on this subject for fear of misrepresenting the author; but, as far as I can judge, his results are quite consistent with those of Tower. *Sempervivum funckii* and *S. acuminatum* were subjected to altered conditions of light and nutrition, with the result that striking variations, such as the transformation of sepals into petals, of petals into stamens, of stamens into petals and into carpels, were produced. Experiments were made on *Sempervivum acuminatum*, with the view of answering the question whether such alterations of flowers can be transmitted. The answer was in the affirmative. The seeds of flowers artificially altered and self-fertilised gave rise to twenty-one seedlings, among which four showed surprising deviations of floral structure. In two of these seedlings all the flowers were greatly altered, and presented some of the modifications of the mother plant, especially the transformation of stamens into petals. These experiments are still in progress, and it would perhaps be premature to

lay too much stress upon them if it were not for the fact that they are so completely confirmatory of the results obtained by similar methods in the animal kingdom.

I submit to you that evidence is forthcoming that external conditions may give rise to inheritable alterations of structure. Not, however, as was once supposed, by producing specific changes in the parontal soma, which changes were reflected, so to speak, upon the gorm-cells. The new evidence confirms the distinctions drawn by Weismann between somatic and germinal variations. It shows that the former are not inherited, while the latter are; but it indicates that the germ may be caused to vary by the action of external conditions in such a manner as to produce specific changes in the progeny resulting from it. It is no more possible at the present time to connect rationally the action of external conditions on the germ-cells with the specific results produced in the progeny than it is possible to connect cause with effect in the experiments of Herbst and Stockard; but, when we compare these two kinds of experiments, we are no longer able to argue that it is inconceivable that such and such conditions acting on the germ-plasm can produce such and such effects in the next generation of adults. We must accept the evidence that things which appeared inconceivable do in fact happen, and in accepting this we remove a great obstacle from the path of our inquiries, and gain a distinct step in our attempts to discover the laws which determine the production of organic form and structure.

But such experiments as those which I have mentioned only deal with one aspect of the problem. They tell us about external conditions and the effects that they are observed to produce upon the organism. They give us no definite information about the internal changes which, taken together, constitute the response of the organism to external stimuli. As Darwin wrote, there are two factors to be taken into account—the nature of the conditions and the nature of the organism—and the latter is much the more important of the two. More important because the reactions of animals and plants are manifold; but, on the whole, the changes in the conditions are few and small in amount. Morphology has not succeeded in giving us any positive knowledge of the nature of the organism, and in this matter we must turn for guidance to the physiologists, and ask of them how far recent researches have resulted in the discovery of factors competent to account for change of structure. Perhaps the first step in this inquiry is to ask whether there is any evidence of internal chemical changes analogous in their operation to the external physical and chemical changes which we have been dealing with.

There is a great deal of evidence, but it is extremely difficult to bring it to a focus and to show its relevancy to the particular problems that perplex the zoologist. Moreover, the evidence is of so many different kinds, and each kind is so technical and complex, that it would be absurd to attempt to deal with it at the end of an address that has already been drawn out to sufficient length. But perhaps I may be allowed to allude to one or two generalisations which appear to me to be most suggestive.

We shall all agree that, at the bottom, production and change of form is due to increase or diminution of the activities of groups of cells, and we are aware that in the higher animals change of structure is not altogether a local affair, but carries with it certain consequences in the nature of correlated changes in other parts of the body. If we are to make any progress in the study of morphogeny, we ought to have as exact ideas as possible as to what we mean when we speak of the activities of cells and of correlation. On these subjects physiology supplies us with ideas much more exact than those derived from morphology.

It is, perhaps, too sweeping a generalisation to assert that the life of any given animal is the expression of the sum of the activities of the enzymes contained in it, but it seems well established that the activities of cells are, if not wholly, at all events largely, the result of the actions of the various kinds of enzymes held in combination by their living protoplasm. These enzymes are highly susceptible to the influence of physical and chemical media, and it is because of this susceptibility that the organism responds to changes in the environment, as is clearly illustrated in a particular case by Tower's experiments on the production of colour changes in potato-beetles. Bayliss and Starling have shown that in lower animals, protozoa and sponges, in which no nervous system has been developed, the response of the organism to the environment is effected by

purely chemical means. In protozoa, because of their small size, the question of coadaptation of function hardly comes into question; but in sponges, many of which are of large size, the mechanism of coadaptation must also be almost exclusively chemical. Thus we learn that the simplest and, by inference, the phyletically oldest mechanism of reaction and co-ordination is a chemical mechanism. In higher animals the necessity for rapid reaction to external and internal stimuli has led to the development of a central and peripheral nervous system, and as we ascend the scale of organisation, this assumes a greater and greater importance as a co-ordinating bond between the various organs and tissues of the body. But the more primitive chemical bond persists, and is scarcely diminished in importance, but only overshadowed by the more easily recognisable reactions due to the working of the nervous system. In higher animals we may recognise special chemical means whereby chemical coadaptations are established and maintained at a normal level, or under certain circumstances altered. These are the internal secretions produced by sundry organs, whether by typical secretory glands (in which case the internal secretion is something additional and different from the external secretion), or by the so-called ductless glands, such as the thyroid, the thymus, the adrenal bodies, or by organs which cannot strictly be called glands—namely, the ovaries and testes. All these produce chemical substances which, passing into the blood or lymph, are distributed through the system, and have the peculiar property of regulating or exciting the specific functions of other organs. Not, however, of all the organs, for the different internal secretions are more or less limited and local in their effects: one affecting the activity of this and another the activity of that kind of tissue or organ. Starling proposed the name hormones for the internal secretions because of their excitatory properties (ὁρμάω, to stir up, to excite).

Hormones have been studied chiefly from the point of view of their stimulating effect on the metabolism of various organs. From the morphologist's point of view, interest chiefly attaches to the possibility of their regulating and promoting the production of form. It might be expected that they should be efficient agents in regulating form, for, if changes in structure are the result of the activities of groups of cells, and the activities of cells are the results of the activities of the enzymes which they contain, and if the activities of the enzymes are regulated by the hormones, it follows that the last-named must be the ultimate agents in the production of form. It is difficult to obtain distinct evidence of this agency, but in some cases at least the evidence is sufficiently clear. I will confine myself to the effects of the hormones produced by the testes and ovaries. These have been proved to be intimately connected with the development of secondary sexual characters[1]—such, for instance, as the characteristic shape and size of the horns of the bull; the comb, wattles, spurs, plumage colour, and spurs in poultry; the swelling on the index finger of the male frog; the shape and size of the abdominal segments of crabs. These are essentially morphological characters, the results of increased local activity of cell-growth and differentiation. As they are attributable to the stimulating effect of the hormone produced by the male organ in each species, they afford at least one good instance of the production of a specific change of form as the result of an internal chemical stimulus. We get here a hint as to the nature of the chemical mechanism which excites and correlates form and function in higher organisms; and, from what has just been said, we perceive that this is the most primitive of all the animal mechanisms. I submit that this is a step towards forming a clear and concrete idea of the inner nature of the organism. There is one point, and that a very important one, upon which we are by no means clear. We do not know how far the hormones themselves are liable to change, whether by the action of external conditions or by the reciprocal action of the activities of the organs to which they are related. It is at least conceivable that agencies which produce chemical disturbances in the circulating fluids may alter the chemical constitution of the hormones, and thus produce far-reachng effects. The pathology of the thyroid gland gives some ground for belief that such changes may be produced by the action of external conditions. But, however this may be, the line of reasoning that we have followed

[1] See J. T. Cunningham, "The Heredity of Secondary Sexual Characters in relation to Hormones, a Theory of the Inheritance of Somatogenic Characters." *Archiv f. Entwicklungsmechanik*, xxvi., 1908.

raises the expectation that a chemical bond must exist between the functionally active organs of the body and the germ-cells. For if, in the absence of a specialised nervous system, the only possible regulating and coadapting mechanism is a chemical mechanism, and if the specific activities of a cell are dependent on the enzymes which it holds in combination, the germ-cells of any given animal must be the depository of a stock of enzymes sufficient to insure the due succession of all its developmental stages as well as of its adult structure and functions. And as the number of blastomeres increases, and the need for co-ordination of form and function arises, before ever the rudiments of a nervous system are differentiated, it is necessary to assume that there is also a stock of appropriate hormones to supply the chemical nexus between the different parts of the embryo. The only alternative is to suppose that they are synthesised as required in the course of development. There are grave objections to this supposition. All the evidence at our disposal goes to show that the potentialities of germ-cells are determined at the close of the maturation divisions. Following the physiological line of argument, it must be allowed that in this connection 'potentiality' can mean nothing else than chemical constitution. If we admit this, we admit the validity of the theory advanced by more than one physiologist that heritable 'characters' or 'tendencies' must be identified with the enzymes carried in the germ-cells. If this be a true representation of the facts, and if the most fundamental and primitive bond between one part of an organism and another is a chemical bond, it can hardly be the case that germ-cells—which, *inter alia*, are the most primitive, in the sense of being the least differentiated, cells in the body—should be the only cells which are exempt from the chemical influences which go to make up the co-ordinate life of the organism. It would seem, therefore, that there is some theoretical justification for the inheritance of induced modifications, provided that these are of such a kind as to react chemically on the enzymes contained in the germ-cells.

One further idea that suggests itself to me and I have done. Is it possible that different kinds of enzymes exercise an inhibiting influence on one another; that germ-cells are 'undifferentiated' because they contain a large number of enzymes, none of which can show their activities in the presence of others, and that what we call 'differentiation' consists in the segregation of the different kinds into separate cells, or perhaps, prior to cell-formation, into different parts of the fertilised ovum, giving rise to the phenomenon known to us as prelocalisation? The idea is purely speculative; but, if it could be shown to have any warrant, it would go far to assist us in getting an understanding of the laws of the production of form.

I have been wandering in territories outside my own province, and I shall certainly be told that I have lost my way. But my thesis has been that morphology, if it is to make useful progress, must come out of its reserves and explore new ground. To explore is to tread unknown paths, and one is likely to lose one's way in the unknown. To stay at home in the environment of familiar ideas is no doubt a safe course, but it does not make for advancement. Morphology, I believe, has as great a future before it as it has a past behind it, but it can only realise that future by leaving its old home, with all its comfortable furniture of well-worn rules and methods, and embarking on a journey, the first stages of which will certainly be uncomfortable and the end is far to seek.

FRIDAY, SEPTEMBER 2.

Joint Meeting with Section K.

The following Papers were read :—

1. *The New Force, Mitokinetism. By* Professor MARCUS HARTOG, *D.Sc.*

On the discovery of the cell-field in karyokinesis its analogy with that of two opposite magnetic or electric poles was at once recognised. This analogy was developed towards the beginning of the present century, especially by Reinke, Ziegler, and Gallardo. A little later it fell to the author to complete the gaps

in the theory by pointing out that the material visible structures of the polar stars and spindle were not the abstract 'lines of force' of Faraday and Clerk-Maxwell, but material 'chains of force' of more permeable substance than the rest of the field, held in position by the stresses radiating from the unlike poles. This is in brief a statement of what we may call the 'heteropolar hypothesis.' On the other hand, Rhumbler, Bütschli, and Leduc put forward the view that the spindle was due to diffusion currents centred on its poles. The two former failed to realise that diffusion currents centred on two like poles (two sources, or two sinks to use Clerk-Maxwell's metaphor, taken from stream lines) could not produce the spindle, but the anti-spindle or crossed figure, just the same as two 'like' magnetic or electric poles. Leduc, when he realised that the centrosomes of the animal cell were 'like' in respect to osmotic phenomena, immediately tried to show that the cell spindle was no true spindle, but a mock one, formed of two asymmetrical spindles touching by their wide ends. But the figure obtained in his models was, unlike the cell spindle, *discontinuous* across the equator. Nevertheless, it had the effect of inducing Gallardo to try to get better models. Gallardo, like others, was impressed by two facts: (1) the centrosomes diverge as the spindle grows; (2) Lillie had shown that the chromosomes bear a positive electrostatic charge and must repel each other.

The answer to (1) is that in many cases the centrosomes show the effects of a bodily pull exercised by the cytoplasm ('cytoplasmic traction' of Hartog). This is well shown in the enormous cell-figures of *Rhynchelmis*, where the centrosomes actually give way under the contrary pulls; and in several worms and molluscs, where the whole figure is spirally twisted, proving that the pull is accompanied by a twist. Moreover, the separation of the poles during the process of karyokinesis is not universal, as noted and figured by Kostanecki and figured without remark by Yatsu.

The answer to (2) is that Pentimalli has shown that while the living chromosomes migrate towards the anode of a constant current, the achromatic spindle is not affected in the same way, but only yields to the mechanical push exerted by the chromosomes.

Gallardo has sought to model electrically the spindle between like poles, with two closely apposed broad inductors of one sign to represent the 'equatorial plate,' and two small poles of the opposite sign for the centrosome. It is impossible in this way to represent the interzonal fibres between the two disceding groups of chromosomes in anaphase.

His last model is what we may term an osmoto-electrolytic model. His field is of mucilage; the centro-poles are drops of solution of acid fuchsin, his equatorial band of (basic) brilliant green; while the indicators are powdered (basic) fuchsin dusted on the surface of the gum, which leave behind a comet-like trail of red as they travel away from the central band to either pole. The central band itself tends to split, and its two halves are united by cross bands of green solution which simulate in position and in outward bulge the interzonal bands; and this gives a most striking character to the model. If two like poles are united by tenacious threads their lateral repulsion and their tenacity result in a good geometrical spindle, as is shown in the electrostatic model figured by the author; but if these threads are severed they at once assume the direction of the anti-spindle, and this is the crucial point.

The absolute proof of the opposite polarity of the two centrosomes is to be found in the growth of the spindle by inflection and coalescence of rays growing out from the centrosomes. In some cases the spindle is actually formed *ab initio* in this way.

Gallardo has stated that no spindle can be formed in the absence of chromosomes, and this is essential to his view. But the spindle in the animal cell everywhere is free from chromosomes at first; and several cases may be cited, besides Bonnevie's, of the formation of full-grown spindles without any equatorial plate.

Since it is demonstrated that the cell-spindle is homopolar with respect to osmosis, currents, electrolytic, or electrostatic force, magnetism is out of the question, we may conclude that mitokinetism is a *new* force unknown so far outside the living cell.

2. *A Cytological Study of Artificial Parthenogenesis in* Strongylocentrotus purpuratus. *By* EDWARD HINDLE, *Ph.D., A.R.C.S.*

This investigation was undertaken mainly with the object of tracing the cytological changes that follow the chemical fertilisation of sea-urchin eggs by means of a monobasic fatty acid, followed by treatment with hypertonic salt solution.

The experimental part of the work was performed, under the direction of Professor Loeb, at Pacific Grove during the month of January 1910. The eggs of *S. purpuratus* were obtained by removing the gonads from a female and allowing them to remain in a dish of sterilised sea-water for a few hours, when the ripe eggs drop out of the ovaries and fall to the bottom of the dish.

Membrane-formation was effected by putting the eggs in a mixture of 50 c.c. sea-water + 2·9 c.c. of $\frac{N}{10}$ butyric acid for from 90 to 150 seconds. On transferring them from this mixture to normal sea-water the eggs then formed fertilisation membranes. Some of these eggs were allowed to develop without further treatment, but at ordinary temperatures (15° C.) very few of them completed even the first division.

When the eggs from the butyric-acid solution had remained in normal sea-water for about 20 minutes they were then placed into a mixture of 50 c.c. sea-water + 8 c.c. of $2\frac{1}{2}$ N – NaCl, and exposed to the action of this solution for times varying from 30 to 60 minutes. Finally, the eggs were again transferred to normal sea-water; and if the periods of exposure had been correctly chosen, practically all of them developed and gave rise to free-swimming larvæ, indistinguishable in form and behaviour from those that develop from normally fertilised eggs.

The developing eggs were fixed at various stages, imbedded in paraffin, sectioned and stained in the usual way.

A. *After treatment of the eggs of* Strongylocentrotus purpuratus *with butyric acid alone the following changes were observed:—*

1. The first change is the starting of a process of cytolysis as a result of the solution or liquefaction of the ectoplasmic layer immediately within the outer membrane of the egg. As a result of this cytolysis the surface membrane becomes lifted away from the protoplasm of the egg and appears distinct.

That the formation of this fertilisation membrane is due to a process of cytolysis is proved by the fact that almost any cytolytic agent is able to produce it (acids, alkalies, digitalin, solanin, saponin, fat solvents, alcohol, distilled water, blood-serum, &c.).

2. The membrane-formation is accompanied by an alteration in the appearance of the nucleolus, which, from being a densely staining mass of chromatic substance, changes to a lightly staining body of somewhat indefinite shape, or may even break down into two or more lesser bodies.

3. A dissolution of the cytoplasmic granules in the immediate neighbourhood of the nucleus results in the appearance of a clear perinuclear zone. Probably as a result of currents flowing centripetally from the cytoplasm towards the nucleus, radiations appear in and around this zone.

4. The appearance of this perinuclear zone is succeeded by a period of nuclear growth.

5. In eggs that are developing at ordinary temperatures a large monaster is usually developed, its rays centring in the nucleus. The nuclear membrane disappears and the chromatin breaks up into eighteen chromosomes. These may undergo division and be drawn out of the nuclear area along the rays, in which case they appear scattered throughout the cytoplasm. A reduction of the astral rays may be followed by reconstruction of the original nucleus with an increased number of chromosomes, and this process may be repeated two or three times. Such eggs never divide, but simply disintegrate.

6. Eggs developing at a low temperature (2° to 5° C.) may complete the first few divisions.

7. Cytasters have never been observed.

B. *After treatment with butyric acid, followed by hypertonic salt solution* (Loeb's improved method).

8. The interval between treatment with butyric acid and the hypertonic salt solution is characterised by the membrane-formation and an alteration in the staining properties of the nucleolus. These changes are accompanied by the appearance of a clear perinuclear zone, as described above (3).

9. During the treatment with hypertonic salt solution there is a slight increase in the size of the nucleus.

10. After transference of the eggs back into normal sea-water the perinuclear zone still further develops, and is followed by growth of the nucleus.

11. A typical cleavage aster is formed by the division of a centrosome, that first appears on the nuclear membrane.

12. A varying number of cytasters may appear. If excessively developed they interfere with the normal division of the cell, and multipolar spindles are formed. The cytasters are only developed in eggs that have remained too long in the hypertonic solution.

13. The chromatin breaks up into eighteen chromosomes, which is half the number occurring in normally fertilised eggs. The reduced number of chromosomes (eighteen) persists in the cells of the parthenogenetic larvæ at least as far as the free-swimming blastula, and beyond this stage it is impossible to count them, owing to the small size of the cells.

In conclusion, the suggestion is offered that the known facts of artificial parthenogenesis may be competent to explain the origin of cancer.

The following Papers and Reports were then read in Section D :—

1. *Note on the Biology of Teleost and Elasmobranch Eggs.* *By* W. J. Dakin, *D.Sc.*

Observations made by the author two years ago confirmed the results of experiments made by Botazzi and others which indicated that the osmotic pressure and salinity of the blood of marine teleosts was very different from that of the external medium in which they lived, but showed, however, that the osmotic pressure and salinity of the blood was affected by changes in the salinity of the water. The blood of the eel has a lower osmotic pressure in fresh water than in the sea. The blood of fresh-water fishes is less saline than that of marine fishes.

The osmotic pressure of the blood of elasmobranchs is almost identical with that of the sea water in which they live.

Does the egg-contents or body-contents of young teleost larvæ bear the same relation to the sea water as the blood of the adult fish?

Experiments have shown that the specific gravity of plaice eggs can be altered by varying the salinity of the water in which they are living. The egg-contents are therefore not altogether independent of the sea water. At the same time, by determinations of the freezing-point, and consequently direct measurements of the osmotic pressure of the egg-contents, it was shown that the salinity and osmotic pressure was very much less than that of the medium in which the eggs were living and about the same as that of the blood of the adult fish.

There is therefore an equilibrium between the sea water and the egg-contents which does *not* consist in an equality of osmotic pressures; and while both osmotic pressures are very different, a change in that of the water produces a small but definite change in that of the egg-contents.

Death of the eggs destroys the conditions under which this equilibrium is sustained, and the egg-contents increase in salinity by reason of the influence of the surrounding sea water. A corresponding increase in specific gravity takes place, and the egg is no longer able to float.

The osmotic pressure of elasmobranch eggs is very different from that of teleost eggs, though both may be living in water of the same salinity. The relation existing between the egg-contents of dog-fish eggs and the water is the same as that between the blood of the adult fish and the medium in which they live.

Abstract of Freezing-point Determinations.

	°C.
Δ of sea water	−1·91
Δ of egg-contents of *Pleuronectes platessa*	−0·70
Δ of blood of *P. platessa*	−0·75
Δ of egg-contents of dog-fish eggs	−1·80
Δ of blood of adult fish	−1·90

2. *Coccidia and Coccidiosis in Birds.* *By* H. B. Fantham, *D.Sc., B.A., A.R.C.S.*

One of the great causes of death in young birds, such as grouse and pheasants, is popularly known as 'enteritis,' one of the symptoms being diarrhœa. The term enteritis has been used to cover many intestinal derangements, but one of the chief forms of it is now known definitely, and has also been proved experimentally to be due to Coccidia, microscopic, parasitic Protozoa belonging to the class Sporozoa. The pathogenic agent in grouse, fowls, and pheasants is known as *Eimeria* (*Coccidium*) *avium.*

Coccidia are responsible for fatal epizoötics among grouse chicks, pheasants, fowls, turkeys, geese, ducks, and other birds, and hence the study of the pathogenic organisms is of great economic importance. Resistant oöcysts of the parasite are voided in the fæces of the infected birds, and are acquired by other birds in their food or drink. A mature oöcyst contains four sporocysts, in each of which two active, motile germs or sporozoites are developed. The oöcysts are swallowed by the birds, and under the influence of the pancreatic juice the cyst walls are softened, the sporozoites creep out and penetrate the epithelial cells of the duodenum of the host. There they become rounded and grow, passively feeding on the host cell.

After attaining a certain size, the parasites—now schizonts—proceed to multiply. Nuclear division occurs, the nuclei migrate to the periphery of the cell, cytoplasm segregates round each nucleus, and a cluster of daughter germs or merozites arranged "en barillet," *i.e.*, like the segments of an orange, is produced. Very little residual protoplasm remains after the formation of merozoites. The groups of merozoites break up and the small, vermicular parasites glide away and invade other cells, there to grow and multiply in exactly the same way as did their parent cell. A number of generations of merozoites is produced, and the destruction of the epithelium, due to their action and the digestive derangements resulting therefrom, are sufficient to cause the death of the host in some cases. But in most instances some merozoites pass down into the cæca, where they grow and multiply, producing intense inflammation.

Sooner or later a limit is reached both to the power of the bird to provide nourishment for the parasite and to the multiplicative capacity of the parasite itself, and then sexual forms are produced. Some Coccidia become large and massive and contain much reserve food-material. These are the macrogametocytes or female mother cells, each of which gives rise to a single macrogamete (♀). Slightly smaller parasites (microgametocytes) undergo nuclear multiplication and give rise to many minute, biflagellate microgametes (♂). The groups of microgametes disperse and each microgamete swims away in search of the macrogamete. The latter invests itself precociously with a cyst wall, in which a micropyle is left for the entry of the microgamete. One microgamete only fuses with the macrogamete—the process has been watched in life—and the oöcyst wall is then completed by the closure of the micropyle. The oöcysts may vary somewhat in size and shape.

At first the oöcysts are uninucleate and their contents completely fill them. The contents then concentrate into a spherical mass, either at the centre or nearer to one end. The nucleus divides into four, and around each nucleus protoplasm aggregates, forming four round sporoblasts. Each sporoblast develops into an oval sporocyst, inside which two sporozoites are formed.

Coccidiosis is accompanied by an increase in the number of polymorphonuclear leucocytes in the blood, together with a decrease in the number of the erythrocytes.

Young birds are much more susceptible to coccidiosis than older ones, but older birds that have become chronics serve as reservoirs of oöcysts and constant sources of infection. In this connection infected foster-mothers of hand-reared pheasants serve to infect young broods.

Lime dressing of the soil, which destroys oöcysts, is the most effective treatment devised at present for combating coccidiosis. Either a little ferrous sulphate, or a weak solution of catechu added to the drinking water is of service.

All infected corpses should be burned and not buried, as oöcysts remain infective in the soil for long periods.

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3. *First Results from the Oxford Anthropometric Laboratory.* *By* EDGAR SCHUSTER, *D.Sc.*

The laboratory was started by Professor Bourne in January 1908, with the following objects, among others :—(1) To obtain a statistical survey of the physical development of undergraduates. (2) To ascertain what bodily changes or developments take place during a man's residence in Oxford as an undergraduate, and whether such changes depend at all on what games he plays, what school he reads for, and so on.

The following measurements and tests are applied. (1) *Acuity of vision*; (2) *spot pattern test.* This test was devised by Dr. McDougall, and is intended to measure the power of concentration. A pattern made by pricking nine holes in a piece of cardboard is shown to the subject for a small fraction of a second by means of an electric light placed behind it and a photographic shutter. After seeing the pattern five times in this way, he is asked to make a map of it on squared paper. This he probably fails to do correctly; he is then shown the pattern five times again and is asked to make a fresh map; and so on until he gets it right. Some interesting results have been obtained with this test, for it has been found that the scholars and exhibitioners are distinctly better at it than commoners; secondly, that men who subsequently took first and second classes in the Final Schools were better than those who took lower classes; and, thirdly, that men reading science and mathematics were, on the whole, better than those reading other subjects. (3) *Lung capacity, measured* with a spirometer. (4) Stature, standing, sitting, and kneeling, from which are deduced length of leg and length of thigh. (5) *Weight.* (6) *Strength of pull*; and also the following *head measurements* : length, breadth, auricular height, horizontal circumference, sagittal arc, transverse arc.

In treating the material the men are divided into groups according to age, and each age group is considered separately. The averages, standard deviations, and various correlation coefficients have been found for each group. The strength of pull and lung capacity increased considerably with age. Stature, weight, and head length also show a similar tendency, but not to so marked an extent.

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4. *Report on the Occupation of a Table at the Zoological Station, Naples.* See Reports, p. 165.

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5. *Report on the Index Animalium.*—See Reports, p. 167.

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6. *Twentieth Report on the Zoology of the Sandwich Islands.* See Reports, p. 167.

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7. *Interim Report on Zoology Organisation.*—See Reports, p. 168.

8. *Report on the Occupation of a Table at the Marine Laboratory, Plymouth.*—See Reports, p. 168.

9. *Report on the Biological Problems incidental to the Iniskea Whaling Station.*—See Reports, p. 168.

10. *Third Report on Experiments in Inheritance.* See Reports, p. 169.

11. *Second Report on the Feeding Habits of British Birds.* See Reports, p. 169.

MONDAY, SEPTEMBER 5.

Joint Meeting with Sub-section B (Agriculture).—See p. 583.

The following Papers were read in Section D:—

1. *Some Experiments and Observations on the Colours of Insect Larvæ. By* Professor W. GARSTANG, *D.Sc.*

2. *Comparison of the Early Stages of Vertebrates. By* Professor C. S. MINOT.

3. *Insect Coloration and Environment. By* MARK L. SYKES.

4. *A Preliminary Note on the Formation and Arrangement of the Opercular Chætæ of* Sabellari. *By* ARNOLD T. WATSON, *F.L.S.*

Of the peculiarities of structure characteristic of the family to which these sedentary, tube-building Polychaete worms belong, the greatest interest attaches to the processes called by different zoologists by the names 'Kopflappen,' 'Paleeutuäger,' 'Cephalic lobes,' or 'Peristomial lobes.' Their position in relation to the head of the animal has favoured the idea of their being Cephalic lobes, but such an arrangement would be exceptional, and it seems more likely that they are derived from the anterior parapodia, a view which seems to be supported by the present observations. These lobes, which are united dorsally at their bases, but are free terminally, bear on their ventral face a series of rows of tentacles, their crescent-shaped distal extremities being armed with three concentric rows of paleæ, each of characteristic form. The armed crescents of the two lobes, when drawn together, form the operculum defending the entrance to the tube on retreat of the inmate. Viewed from above the exposed portions of the paleæ of the outer row are seen to be arranged in an imbricated manner, their free ends directed outwards; the paleæ of the middle row also are slightly imbricated, their free ends, too, being directed outwards; the free ends of the innermost row, the chætæ of which alternate in position with the last-named, are directed inwards and upwards. From the exposed portions of each palea an extension in the form of a long curved shaft descends at an angle of 120° or

more, into the tissue of the lobe. From a very early stage in the life of the worm the form of these chætæ changes but little, except in regard to size, which increases, of course, with the growth of the worm. It is evident that during life new chætæ must be constantly in course of formation to replace the older ones which are cast off, and the peculiarity of form and complexity of arrangement suggested that special provisions might be expected. By means of serial sections but little information could be obtained, but on rendering the lobes transparent it was found that, running lengthwise in each lobe, there exist two 'nests' for the formation of the chætæ, the outer one supplying the outer paleæ, and the inner one supplying the middle and innermost paleæ, which are packed alternately in the 'nest.' The paleæ develop in the 'nest,' commencing as minute hooked or angular particles, and chætæ in an advanced stage can be clearly seen travelling through the tissue in a somewhat spiral fashion in order to reach in rotation the positions which they respectively take up at the dorsal end of each opercular crescent. The foregoing remarks refer to *Sabellaria alveolata*, and apply equally to *Sabellaria spinulosa*; but in the latter species I have discovered in each lobe two or three long curved acicular dorsal chætæ in addition to the three rows of chætæ which form the operculum. In certain members of the family (*Pallasia*) the operculum is armed with two rows of chætæ only, but there exist in addition two or more hooks, placed dorsally, in position corresponding with the acicula above mentioned. These hooks have been considered by some zoologists homologous with the missing middle row of opercular chætæ, but in view of the existence of the dorsal chætæ of *Sabellaria spinulosa*, in addition to the complete three rows of opercular chætæ, such a view scarcely seems tenable.

The above are, of course, only notes on an episode in the formation of the operculum, to the minuter details of which I hope to give further attention.

TUESDAY, SEPTEMBER 6.

The following Papers were read :—

1. *Sex and Immunity. By* GEOFFREY SMITH, *M.A.*

One of the principal effects which a parasite may exert on its host is to confer immunity upon it. Immunity to a poison or poisonous organism is due to the presence in the blood or body fluids of a substance or substances which combine in some manner with the poisonous substances and prevent them reaching the tissues in an active form. Ehrlich has given a graphic representation of this process in his side-chain theory, according to which an organic poison when it enters the body anchors itself to certain side-chains of the protoplasmic molecules, and these being unable to take up nourishment are regenerated in excess and cast off into the blood stream, where they act as antibody by seizing on the poison and preventing it reaching the tissues.

Besides the well-known phenomenon of immunity a peculiar effect of parasites on their hosts, especially among the invertebrata, is found in the *Castration Parasitaire* of Giard. It has been found that the presence of certain parasites causes the atrophy and sometimes the disappearance of the gonads of the host, together with peculiar changes in the secondary sexual characters. A careful analysis of a particular instance (the parasite *Sacculina* on the spider crab *Inachus*) has shown that the real effect of the parasite is to cause the male host to assume *adult female characters* externally and after the death of the parasite internally as well, large ova being produced from the testes; and in the case of the female host the effect is really the same, as the young infected females are forced to assume *adult female characters* at a premature stage. (See Q.J.M.S., vol. 54, p. 577, and vol. 55, p. 225.) The object of this paper is to suggest that this peculiar reaction to the presence of a parasite is really an immunity phenomenon.

We have seen that the effect of *Sacculina* on *Inachus* is to make the latter become adult female in character. Now the most important adult female character

in a normal *Inachus* is the elaboration of a large quantity of yolk in the ovary which fills about half the body. In an infected *Inachus* of either sex with atrophied gonad this process of yolk-elaboration can be proved to occur since the *Sacculina* roots manufacture yolk very similar to the ovarian yolk of a normal female *Inachus* from the blood of the host. The parasite *Sacculina*, therefore, forces the *Inachus*, whether male or female, to produce substances in the blood from which it can manufacture yolk. As fast as these substances are produced the *Sacculina* takes them up, and by anchoring them stimulates their continued reproduction. These female yolk-forming substances, saturating the body fluids of infected crabs both male and female, cause the development of the female secondary sexual characters, and when the parasite dies and its roots no longer assimilate the yolk-forming substances, they are taken up by the remains of the gonad which consequently proceeds to form ova. In the case of *Peltogaster* on *Eupagurus*, Potts (Q.J.M.S., vol. 50, p. 599) has shown that small ova are formed in the testes of the host while the parasite is still alive, so that here the excess of the yolk-forming substances is taken up by the gonad during the life of the parasite. This overproduction of a substance which is being anchored by a parasite is closely analogous to the production of antibody in immunisation. The crab doubtless benefits by supplying the *Sacculina* with the yolk-forming substance, as it thus protects other nutritional substances necessary for its vital organs from being abstracted by the parasite. In this manner it is possible to bring the isolated and hitherto inexplicable phenomenon of parasitic castration into the well-known category of immunity.

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2. *Coral Snakes and Peacocks.* *By* Dr. H. F. Gadow, *F.R.S.*

3. *Relation of Regeneration and Developmental Processes.* *By* Dr. J. W. Jenkinson.

In a broad sense ontogeny is distinguished from phylogeny; in a narrow, as the development of an organism from an egg-cell, from budding and regeneration.

In development the three processes of cell and nuclear division, growth and differentiation are easily recognised. Differentiation—the main problem—is determined by external factors, a definite constitution of the physical and chemical environment being necessary, and internal. The latter are: (1) The initial structure of the germ; (2) the interaction of developing parts.

With regard to (1) Weismann's conception of the qualitative division of the nucleus has been abandoned, for while we know (Boveri) that the chromatin elements in the nucleus are unlike, we also know that each cell of the developing organism must necessarily contain a complete specific set of these elements. We turn then to the cytoplasm and find that experiments prove the existence of definite organ-forming substances in it, arranged in a definite way, and sometimes stratified and graded. This arrangement accounts for the observed progressive restriction of the potentialities of parts. Segmentation segregates these substances into cells, but the order in which the material is cut up is immaterial; the essence of segmentation is to reduce the ratio of cytoplasm to nucleus. In regeneration—the production of a whole structure by a part in a *differentiated* organism—similar processes and factors may be observed.

Regeneration—of both internal and external members—is of practically universal occurrence in the animal kingdom. The regenerate often differs quantitatively or qualitatively (heteromorphosis) from the original. Reversal of polarity is a special case of the latter.

Features common to all regenerations are the covering of the wound, the cell-multiplication (to reduce the cytoplasm-nucleus ratio), growth—always at right angles to the cut surface, and at a rate which alters like the ontogenetic rate —and differentiation. Differentiation follows the ontogenetic order as a rule, but may differ from it (anomalous behaviour of germ-layers). Of the external factors little is known, but it is certain that the actual injury is the prime stimulus. Internal factors are: Interaction of parts, size (there is a minimal size), degree of differentiation (power of regeneration decreases with age), level

or material (necessarily cytoplasmic since the nuclei are all alike), and polarity. Polarity may be expressed in terms of a graded stratification of materials. In fact, to the adult organism there must be attributed the same organ-forming substances as were present in the germ, and similarly arranged. The difficulty is that the former is divided into differentiated cells. A second difficulty is presented by the anomalous behaviour of the germ-layers, and by the fact that a part in which these substances exist *ex hypothesi* in other than the correct proportions can yet form a whole. This indicates that the problem is fundamentally the problem of assimilation, and it should be borne in mind that metabolism and regeneration are just the two functions which depend, in Protozoa, on the presence of the nucleus.

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4. *Semination in* Calidris arenaria: *A Key to some Problems regarding Migratory Movements in the Breeding-Season. By* C. J. PATTEN, *M.A., M.D., Sc.D.*

The positive evidence which I now possess of the occurrence of the Sanderling (*Calidris arenaria*) throughout the summer along various parts of the British coast prompted me to make an examination of the testes with the view of throwing some further light on the question as to the probability of the species breeding in our Isles. From a study of the bird's habits I have already made out several facts which support the view that birds apparently in nuptial plumage, and occurring along the coastlands in our Isles in the height of the breeding-season are not fully matured, and even in their plumage a slight but important difference from the true nuptial garb could be made out. This plumage I have called pre-nuptial,[1] and it is with special reference to birds in such garb that I now put forward the results of my investigations into the condition of the testes at the time when, if active, they should be at the zenith of development.

I shall have but little reference to make regarding birds in true nuptial plumage, seeing that they do not tarry during the vernal migration along our shores more than a few days, and their occurrence with and departure from us always well precedes the time of the commencement of nesting.

The remarkable fact that in birds the testes reach a relatively enormous size during the limited period in which they are functionally active is a point which I have kept carefully in view. I have investigated the state of the testes in a large number of our common birds which are known to start breeding in April and May, and have found that the glands reach their maximum size from a week to a fortnight before the first laying of eggs takes place. When one considers that the testes of small birds (*e.g.*, House-Sparrow, Hedge-Sparrow, Robin, and many others which I have examined) in January are only the size of a pin's head (1 mm. greatest diameter), and in April or May, as the case may be, reach the size of a small bean (average about 1·3 cm. in greatest diameter), it is natural to suppose that if functionally active the testes of the Sanderling should present correspondingly large dimensions at a corresponding period before the female bird begins to lay. In this species the early clutches of eggs are laid about the middle of June, the hatching-season lasting into July. Out of a large series of testes obtained in May and June the greatest measurements did not exceed 5 mm., 3·5 mm. being the average, while in Sanderlings obtained in July the testes were still smaller, averaging 3 mm. in greatest diameter.[2] By early August a further reduction had taken place in the size of the glands, and both naked-eye and microscopical examination showed a marked similarity with the testes of adult birds obtained in mid-winter. In the absence of knowledge as to the size attained by the fully functional testes of the Sanderling, I have noted that in those birds which show close affinities and come under the same family, viz., *Charadriidæ*, and are much about the same size as the Sanderling (Common Sandpiper, Dunlin, Ringed Plover), the testes in May and June were double the size of the largest testes of *Calidris arenaria* obtainable from my collected

[1] *Vide British Association Report*, 1909, p. 505.

[2] Even in many species which breed in April and May the full size of the active testes is almost maintained in July.

series. Here I may add, however, that in a few birds obtained towards the end of April the testes were as large as those of the other Sanderlings obtained a month later, and were probably rapidly on the road to functional activity. But the flocks from which these birds were obtained only tarried a few days on the coast, and I believe that the birds were mature not only from their plumage and behaviour, but also owing to the comparatively large size of the seminiferous tubules, though while spermatogenesis seemed to be commencing, fully formed and ripe sperm-cells (spermatozoa) were not present. Histologically the condition of such testes resembled that maintained in the glands of a mature Hedge-Sparrow procured in late February. Should one have been able to examine the testes of these Sanderlings in the beginning of June they probably would have been 1·2 cm. in greatest measurements and quite functional. In subjecting thin sections to microscopical examination, a striking difference could be made out between those of *Calidris arenaria* and of many shore-birds in which the glands were actively functional. Apart from the countless swarms of spermatozoa which occupied the seminiferous tubules in the latter, the tubules themselves were markedly larger. The proportion between the two is at once manifest when with a $\frac{1}{8}$-in. objective and No. 2 Huygenian eye-piece fitted to the usual 10-in. microscope tube one finds in the active glands a single tubule, in contrast to some forty to sixty tubules of the inactive glands occupying the whole field of the microscope. The testes of the Sanderlings were all embedded in paraffin, cut in ribbons, and mounted as serial sections. The time taken in examining complete series has been considerable. I feel, however, safe in stating that, apart from the phenomenon of semination in the testes of the birds obtained toward the end of April, while a certain amount of spermatogenesis has taken place, this has passed through more or less abortive phases, no real functional activity having been reached. Yet I would not like to insist that no Sanderlings in pre-nuptial plumage breed. The species no doubt varies individually within limits (as in the case with other animals) in arriving at maturity, some birds being more precocious than others. However, with regard to Sanderlings which occur along our shores during the period when they ought to be nesting, those birds not pairing seem to split into small parties and to lead a sort of nomadic life from shore to shore, being somewhat inconspicuous even to the trained observer until about August when they tend to muster; while in September they join company with migrants coming from northern climes, the latter, as a rule, being young birds in first autumn plumage. Thus are formed flocks of young and partially matured birds, hitherto spoken of as adults and young. The fully adult birds apparently arrive later (about October). I do not consider them at all as plentiful along our coastlands. Probably many pass on to southern climes before mid-winter.

Before concluding I may say that there is reason to believe that other species of shore-birds take more than one year to reach maturity, and that prior to this period their desultory migratory movements correspond in the main to those of the Sanderling. Here, then, investigations into the question of semination afford a key in the elucidation of some points of importance dealing with avian migration and geographical distribution.

WEDNESDAY, SEPTEMBER 7.

The following Papers were read :—

1. *The Anatomy and Physiology of* Calma glaucoides. *By* T. J. Evans.

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2. *Some Anatomical Adaptations to the Aquatic Life in Seals.* *By* H. W. Marett Tims, *M.A., M.D.*

Certain anatomical adaptations to life in the water are to be found in all purely aquatic animals, *e.g.*, expansion of the posterior end of the body, modification of the limbs, shortening and practical obliteration of the neck region (as far as external appearance) and modifications of the larynx.

The details of these structural adaptations in the seal have been fully

described by the author in Volume V. of the National Antarctic Expedition Natural History. The object of this paper was to draw attention to the remarkably early stage of fœtal life at which all these adaptive modifications become fully established, and the possible bearing which such facts may have upon the question of the inheritance of acquired characters.

3. *The Temporal Bone in Primates.* *By* Professor R. J. ANDERSON, *M.D.*

The temporal bone is usually regarded as a bone of the cranium, chiefly because of the relations of the petro-mastoid portion. The squamosal has so much to do with the face bones that it might be considered as occupying an intermediate positon. The zygoma brings the temporal squamosal into relation with the jugal, and sometimes the maxilla. The squamosal may reach the jugal apart from the zygomatic connection. The direct relationship of the mandible with the temporal in mammals obviously emphasises the connection of the squamosal with the face. In primates the size of the squamosal varies. It is much reduced in some rodents. It looks like an arch from beneath which the petro-mastoid appears behind and the tympanic in front. The squamosal has a connection with the brain-case in man that looks more evident on the outside of the skull than on the inside. The parietal runs down internally, separating much of the temporal squamosal from the cranial cavity. In Equidæ the facial relationship is most pronounced. The tympanic may have independent mechanical functions also (as in some mammals). The squamosal may preserve its identity for a long time, or during life (as in a gorilla in the Muséum d'Histoire Naturelle de Paris referred to by Le Double), and in the chimpanzee the persistence of the suture is not uncommon. Occasionally the zygomatic and squamose parts are separate. Of this condition, which is due to developmental causes, Meckel and Grüber record instances. Le Double found the squamosal divided. I believe I have met this once in man, and also in the chimpanzee. In the latter the upper triangular part looks like a Wormian bone. The effect of the facial growth on the nutrition of the temporal may lead to two sources of supply being emphasised. The cranial portion may then go with the cranial supply. Three centres of ossification are present in man in the case of the squamosal, one for the zygoma, one for the scale, and a third for the ear part. Four centres may be present. This condition seems rare in primates, and it is difficult to decide upon the normal number. Ossific foci are apt to vary with the nutrition, and that the ossific deposits are very sensitive to such changes an examination of the skulls of primates bred in captivity amply proves.

Le Double gives a second suture in squamosal of Ateles. The anterior range of the temporal depends on the development of the parietal and the sphenoid. A postal process is often found in primate skulls—in one in seven skulls in Australian aborigines. In Papuans the abnormality is rarer, and it is still rarer in white and yellow races. It is the usual thing in gorillas, less common in chimpanzees, much less so in orangs, and less so in gibbons. This connection seems to show a tendency in some types to emphasise the relationship of the temporal with the facial as in ungulates and rodents. Le Double, following Calori, Broca, Grüber, and Virchow, regards the process as theromorph. Anoutchine (Stieda), Rathke, and recently Schwalbe, take a different view. The possibility of the advance being due to the formation of Wormian bones and their subsequent union to the temporal is certain. The tympanic has three ossific foci also. The centre for the styloid process is variable. Owen mentions that the styloform process or angle in gorilla contrasts with the absence of this in chimpanzee.

SECTION E.—GEOGRAPHY.

PRESIDENT OF THE SECTION.—Professor A. J. HERBERTSON, M.A., Ph.D.

THURSDAY, SEPTEMBER 1.

The President delivered the following Address:—

Geography and some of its Present Needs.

Geographical Progress in the Last Decade.

AT the close of a reign which has practically coincided with the first decade of a new century, it is natural to look back and summarise the progress of geography during the decade. At the beginning of a new reign it is equally natural to consider the future. Our new Sovereign is one of the most travelled of men. No monarch knows the World as he knows it; no monarch has ruled over a larger Empire or seen more of his dominions. His advice has been to wake up, to consider and to act. This involves taking existing geographical conditions into account. It will be in consonance with this advice if I pay more attention to the geography of the present and future than to that of the past, and say more about its applications than about its origins. Yet I do so with some reluctance, for the last decade has been one of the most active and interesting in the history of our science.

Among the many geographical results of work in the past decade a few may be mentioned. The measurement of new and the remeasurement of old arcs will give us better data for determining the size and shape of the Earth. Surveys of all kinds, from the simple route sketches of the traveller to the elaborate cadastral surveys of some of the more populous and settled regions, have so extended our knowledge of the surface features of the Earth that a map on the scale of 1 : 1,000,000 is not merely planned, but actually partly executed. Such surveys and such maps are the indispensable basis of our science.

The progress of oceanography has also been great. The soundings of our own and other Admiralties, of scientific oceanographical expeditions, and those made for the purpose of laying cables, have given us much more detailed knowledge of the irregularities of the ocean floor. An international map of oceanic contours, due to the inspiration and munificence of the Prince of Oceanographers and of Monaco, has been issued during the decade, and so much new material has accumulated that it is now being revised. A comparison of the old and new editions of Krümmel's 'Ozeanographie' shows us the immense advances in this subject.

Great progress has been made on the geographical side of meteorology and climate. The importance of this knowledge for tropical agriculture and hygiene has led to an increase of meteorological stations all over the hot belt—the results of which will be of value to the geographer. Mr. Bartholomew's 'Atlas of Meteorology' appeared at the beginning, and Sir John Eliot's 'Meteorological Atlas of India' at the end of the decade. Dr. Hann's 'Lehrbuch' and the new edition of his 'Climatology,' Messrs. Hildebrandsson and Teisserenc de Bort's great work, and the recent studies of the Upper Atmosphere, are among the landmarks of progress. The record is marred only by

the closing of Ben Nevis Observatory at the moment when its work would have been most necessary. To appreciate the progress of Climatology it is only necessary to compare the present number and distribution of meteorological stations with those given in Bartholomew's Atlas of 1899. I have not time to recapitulate the innumerable studies of geographical value issued by many meteorological services, observatories, and observers—public and private—but I may call attention to the improved weather maps and to the excellent pilot charts of the North Atlantic and of the Indian Ocean published monthly by our Meteorological Office.

Lake studies have also been a feature of this decade, and none are so complete or so valuable as the Scottish Lakes Survey—a work of national importance, undertaken by private enthusiasm and generosity. We have to congratulate Sir John Murray and Mr. Pullar on the completion of a great work.

In Geology I might note that we now possess a map of Europe on a scale of 1 : 1,500,000 prepared by international co-operation and also one of North America on a smaller scale; both invaluable to the geographer. The thanks and congratulations of all geographers are due to Professor Suess on the conclusion of his classical work on the Face of the Earth, the first comprehensive study of the main divisions and characteristics of its skeleton. English readers are indebted to Professor and Miss Sollas for the brilliant English translation which they have prepared.

A new movement, inspired mainly by Professor Flahault in France, Professor Geddes in this country, Professors Engler, Drude, and Schimper in Germany, has arisen among botanists, and at last we have some modern botanical geography which is really valuable to the geographer. I wish we could report similar progress in zoological geography, but that, I trust, will come in the next decade.

I pass over the various expensive arbitrations and commissions to settle boundary disputes which have in many cases been due to geographical ignorance, also the important and fascinating problems of the growth of our knowledge of the distribution of economic products and powers, existing and potential, and the new geographical problems for statesmen due to the political and economic revolutions in Japan and China.

It is quite impossible to deal with the exploration of the decade. Even in the past two years we have had Peary and Shackleton, Stein and Hedin, the Duke of the Abruzzi, and a host of others returning to tell us of unknown or little known parts of the globe. We hope to hear soon from Dr. Charcot the results of the latest investigations in the Antarctic. Further work is being undertaken by Scott and his companions; by Bruce, Amundsen, Filchner, and others in the South or North Polar ice worlds; by Longstaff, Bruce, and others in the mountains of India and Central Asia; by Goodfellow and Ryder in New Guinea; and by many other expeditions.

One word of caution may, perhaps, be permitted. There is a tendency on the part of the public to confuse geographical exploration and sport. The newspaper reporter naturally lays stress on the unusual in any expedition, the accidental rather than the essential, and those of us who have to examine the work of expeditions know how some have been unduly boomed because of some adventurous element, while others have not received adequate popular recognition because all went well. The fact that all went well is in itself a proof of competent organisation. There is no excuse for us in this section if we fall into the journalist's mistake, and we shall certainly be acting against the interests of both our science and our section if we do so.

The Position of Geography in the Association.

It was not my intention in this address to raise the question of what is Geography, but various circumstances make it desirable to say a few words upon it. We are all the victims of the geographical teaching of our youth, and it is easy to understand how those who have retained unchanged the conceptions of geography they gained at school many years ago cavil at the recognition of geography as a branch of science. Moreover, the geography of the schools still colours the conceptions of some geographers who have nevertheless done much to make school geography scientific and educational. Many definitions of geography are consequently too much limited by the arbitrary but traditional division of

school subjects. In schools tradition and practical convenience have, on the whole rightly, determined the scope of the different subjects. Geography in schools is best defined as the study of the Earth as the home of Man; its limits should not be too closely scrutinised in schools, where it should be used freely as a co-ordinating subject.

The present division into sections of the British Association is also largely a matter of practical convenience, but we are told that the present illogical arrangement of sections distresses some minds. No doubt there are some curious anomalies. The most glaring, perhaps, is that of combining mathematics with physics—as if mathematical methods were not used in any other subject.

There is undoubtedly a universal tendency to sub-division and an ever-increasing specialisation, but there is also an ever-growing interdependence of different parts of science. The British Association is unquestionably bound to take the latter into account as well as the former. At present this is chiefly done by joint meetings of sections: a wise course, of which this section has been one of the chief promoters. It is possible that some more systematic grouping of sections might be well advised, but such a reform should be systematic and not piecemeal. It is one which raises the whole question of the classification of knowledge. This is so vast a problem and one on which such divergent opinions are held that I must apologise for venturing to put forward some tentative suggestions.

It might be found desirable to take as primary divisions the Mathematical, Physical, Biological, Anthropological, and Geographical groups. Mathematical applications might also be considered in each of the sections which use mathematical notations. In the Physical group there should be the sub-divisions Physics and Chemistry. Each would devote a certain proportion of time to its applied aspects, or these might be dealt with in sub-sections which would include Engineering and Applied Chemistry. In the Biological group there would be Botany, Zoology, in both cases including Palæontology and Embryology, and Applied Biology, which would be dealt with in one or other of the ways I have suggested, and would include Agriculture, Fisheries, &c. (Medicine we leave out at present.) In the Anthropological group, in addition to the present Anthropological and Economics, there should be a section on Psychology, which might or might not be attached to Physiology and have the Education Section as a practical appendage. In the Geographical group there would be Geography and Geology, the practical applications of Geography and Geology being considered in joint meetings with other sections or else in sub-sections—for instance, Geography and Physics for questions of Atmospheric and Oceanic Circulation. Geography and Economics for questions of Transportation, &c.

The Need for Classifications and Notations in Geomorphology, &c.

So much, then, for the classification of Geography with reference to the other sciences. I should like to say a few words about the sub-divisions of Geography and the vexed question of terminology.

In the scheme of the Universe it is possible to consider the Earth as a unit, with its own constitution and history. It has an individuality of its own, though for the astronomer it is only one example of a particular type of heavenly bodies. As geographers we take it as our unit individual in the same way that an anatomist takes a man. We see that it is composed of different parts and we try to discover what these are, of what they are composed, what their function is, what has been their history.

One fundamental division is into land, water, and air. Each has its forms and its movements. The forms are more obvious and persistent in the land. They are least so in the atmosphere, though forms exist—some of which are at times made visible by clouds, and many can be clearly discerned on isobaric charts. The land is the temporarily permanent; the water and atmosphere the persistently mobile; the latter more so than the former. The stable forms of the land help to control the distribution and movements of the waters and to a less extent those of the atmosphere. How great the influence of the distribution of land and water is on the atmosphere may be seen in the monsoon region of Eastern Asia.

The study of the land, the ocean, and the atmosphere has resulted in the

growth of special branches of knowledge—Geomorphology, Oceanography, and Climatology. Each is indispensable to the geographer, each forms an essential part of the geographical whole. Much research work is and will be carried on in each by geographers who find their geographical studies hampered for the lack of it. As geographical progress is to a considerable extent conditioned by progress in these subjects, it would be legitimate to examine their needs. Time, however, will admit only a note on one of the barriers to progress in geomorphology—the lack of a good classification and notation.

Geomorphology deals with the forms of the land and their shaping. Three things have to be kept clearly in view; (i) The structure, including the composition, of the more permanent substance of the form; (ii) The forces which are modifying it; and (iii) The phase in the cycle of forms characteristic of such structure acted on by such forms. We may say that any form is a function of structure, process, and time. The matter is even more complicated, for we have instances, *e.g.* in antecedent drainage systems, of the conditions of a previous cycle affecting a subsequent one—a kind of heredity of forms which cannot be neglected.

The geomorphologist is seeking for a genetic classification of forms, and in the works of Bertrand, Davis, de la Noë and de Margérie, Penck, Richthofen, Suess, and Supan and their pupils are being accumulated the materials for a more complete and systematic classification of forms. As you all know, the question of terms for the manifold land-forms is a difficult one and apt to engender much more controversy than the analysis of the forms themselves. I believe that we shall find it advantageous to adopt some notation analogous to that of the chemists. I have not yet had time to work such a notation out in detail, but it might take the form of using different symbols for the three factors noted above—say, letters for different kinds of structure, Arabic figures for processes, and Roman figures for the stage of a cycle the form has reached.

Take a very simple set of structures and indicate each by a letter :—

			Undisturbed	Faulted
Structure	homogeneous		A	A′
	layered	horizontal	B	B′
		tilted	C	C′
		folded	D	D′
	mixed		E	E′

If pervious or impervious, a *p* or an *i* could be added—*e.g.*, a tilted limestone with faults would be C′*p*.

Next indicate the commoner erosion processes by Arabic numerals :—

Process	moving water	1
	ice	2
	wind	3
	sea	4

One process may have followed another, *e.g.* where a long period of ice erosion has been followed by water erosion we might write 2·1 where these alternate annually, say 21.

The phase of the cycle might be denoted by Roman figures. A scale of V might be adopted and I, III, and V used for youthful, middle-aged, and old-aged, as they have been called; or early, middle, and late phases, as I prefer to term them. II and IV would denote intermediate phases.

A scarped limestone ridge in a relatively mature phase like the Cotswolds would be, if we put the process first—1 C′ III. : A highland like the Southern Uplands of Scotland would be denoted by the formula 1·2·1 E′III.

This is the roughest suggestion, but it shows how we could label our cases of notes, and pigeon-hole our types of forms—and prevent for the present undue quarrelling over terms.[1] No doubt there would be many discussions, for example,

[1] What I wish to make clear is that it is not necessary to invent a new term for every new variety of land form as soon as it is recognised. It will suffice at first to be able to label it. The notation will also stimulate the search for the recognition of new varieties.

about the exact phase of the cycle, whether ice in addition to water has been an agent in shaping this or that form, and so on. But, after all, these discussions would be more profitable than quarrels as to which descriptive term, or place name, or local usage should be adopted to distinguish it.

The use of such notations in geographical problems is not unknown. They were employed by Köppen in his classification of climate; and now in the case of climatology, there is coming to be a general consensus of opinion as to what are the chief natural divisions, and the use of figures and letters to indicate them has been followed by several other authors. This should also be attempted for oceanography.

If any international agreement of symbols and colours could be come to for such things it would be a great gain, and I hope to bring this matter before the next International Geographical Congress.

The Need for Selecting Natural Geographical Units.

We have still to come to Geography proper, which considers land, water, and air not merely separately but as associated together. What are the units smaller than the whole Earth with which our science has to deal?

When we fix our attention on parts of the Earth, and ask what is a natural unit, we are hampered by preconceptions. We recognise species, or genera, or families, or races as units—but they are abstract rather than concrete units. The reason for considering them as units is that they represent an historical continuity. They have not an actual physical continuity, such as the component parts of an individual have. Concrete physical continuity in the present is what differentiates the geographical unit. Speaking for myself, I should say that every visible concrete natural unit on the Earth's surface consisting of more than one organic individual is a geographical unit. It is a common difficulty not to be able to see the wood for the trees; it is still more difficult to recognise that the wood consists of more than trees, that it is a complex of trees and other vegetation, fixed to a definite part of the solid earth and bathed in air. We may speak of a town or State as composed of people, but a complete conception of either must include the spacial connections which unite its parts. A town is not merely an association of individuals, nor is it simply a piece of land covered with streets and buildings; it is a combination of both.

It is true that, in determining the greater geographical units, man need not be taken into account. We are too much influenced by the mobility of man, by his power to pass from one region to another, and we are apt to forget that his influence on his environment is negligible except when we are dealing with relatively small units. The geographer will not neglect man; he will merely be careful to prevent himself from being unduly influenced by the human factor in selecting his major units.

Some geographers and many geologists have suggested that land forms alone need be taken into account in determining these larger geographical units. Every different recognisable land form is undoubtedly a geographical unit. A vast lowland such as that which lies to the east of the Rocky Mountains is undoubtedly a geographical unit of great importance, but its geographical subdivisions are not necessarily orographical. The shores of the Gulf of Mexico could not be considered as geographically similar to those of the Arctic Ocean, even if they were morphologically homologous. The lowlands of the polar regions are very different from those at or near the tropics. The rhythm of their life is different, and this difference is revealed in the differences of vegetation.

I wish to lay great stress on the significance of vegetation to the geographer for the purposes of regional classification. I do not wish to employ a biological terminology nor to raise false analogies between the individual organism and the larger units of which it is a part, but I think we should do well to consider what may be called the life or movement going on in our units as well as their form. We must consider the seasonal changes of its atmospheric and of its water movements, as well as the parts of the Earth's crust which they move over and even slightly modify. For this purpose a study of climatic regions is as necessary as a study of morphological regions, and the best guides to the climatic regions are the vegetation ones.

By vegetation I mean not the flora, the historically related elements, but

the vegetable coating, the space-related elements. Vegetation in this sense is a geographical phenomenon of fundamental importance. It indicates quality—quality of atmosphere and quality of soil. It is a visible synthesis of the climatic and edaphic elements. Hence the vast lowlands of relatively uniform land features are properly divided into regions according to vegetation—tundra, pine forest, deciduous forest, warm evergreen forest, steppe, and scrub. Such differences of vegetation are full of significance even in mountainous areas.

The search after geographical unity—after general features common to recognisable divisions of the Earth's surface, the analysis of these, their classification into types, the comparisons between different examples of the types—seem to me among the first duties of a geographer. Two sets of studies and maps are essential—topographical and vegetational—the first dealing with the superficial topography and its surface irregularities, the latter relating to the quality of climate and soil. Much has been said in recent years—more particularly from this Presidential chair—on the need for reliable topographical maps. Without such maps no others can be made. But when they are being made it would be very easy to have a general vegetational map compiled. Such maps are even more fundamental than geological maps, and they can be constructed more rapidly and cheaply. Every settled country, and more particularly every partially settled country, will find them invaluable if there is to be any intelligent and systematic utilisation of the products of the country. Possessing both sets of maps the geographer can proceed with his task.

This task I am assuming is to study environments, to examine the forms and qualities of the Earth's surface, and to recognise, define, and classify the different kinds of natural units into which it can be divided. For these we have not as yet even names. It may seem absurd that there should be this want of terms in a subject which is associated in the minds of most people with a superfluity of names. I have elsewhere suggested the use of the terms major natural region, natural region, district, and locality to represent different grades of geographical units, and have also attempted to map the seventy or eighty major natural regions into which the Earth's surface is divided, and to classify them into about twenty types. These tentative divisions will necessarily become more accurate as research proceeds, and the minor natural regions into which each major natural region should be divided will be definitely recognised, described, and classified. Before this can be done, however, the study of geomorphology and of plant formations must be carried far beyond the present limits.

The value of systematic and exhaustive studies of environment such as those I suggest can hardly be exaggerated. Without them all attempts to estimate the significance of the environment must be superficial guesswork. No doubt it is possible to exaggerate the importance of the environmental factor, but it is equally possible to undervalue it. The truly scientific plan is to analyse and to evaluate it. Problems of the history of human development as well as those of the future of human settlements cannot be solved without this. For the biologist, the historian, the economist, the statesman this work should be carried out as soon and as thoroughly as is possible in the present state of our knowledge.

A beginning of systematic geographical studies has also been made at the opposite end of the scale in local geographical monographs. Dr. H. R. Mill, one of the pioneers of geography in this country and one of my most distinguished predecessors in this chair, has given us in his study of south-west Sussex an admirable example of the geographical monograph proper, which takes into account the whole of the geographical factors involved. He has employed quantitative methods as far as these could be applied, and in doing so has made a great step in advance. Quantitative determinations are at least as essential in geographical research as the consideration of the time factor. At Oxford we are continuing Dr. Mill's work. We require our diploma students to select some district shown on a sheet of this map for detailed study by means of map measurements, an examination of statistics and literature which throw light on the geographical conditions, and, above all, by field work in the selected district. Every year we are accumulating more of these district monographs, which ought, in their turn, to be used for compiling regional monographs dealing with the larger natural areas. In recent years excellent examples of such regional monographs have come from France and from Germany.

The geomorphologist and the sociologist have also busied themselves with particular aspects of selected localities. Professor W. M. Davis, of Harvard, has published geomorphological monographs which are invaluable as models of what such work should be. In a number of cases he has passed beyond mere morphology and has called attention to the organic responses associated with each land form. Some of the monographs published under the supervision of the late Professor Ratzel, of Leipzig, bring out very clearly the relation between organic and inorganic distributions, and some of the monographs of the Le Play school incidentally do the same.

The Double Character of Geographical Research.

To carry on geographical research, whether on the larger or the smaller units, there is at present a double need, in the first place of collecting new information, and in the second place of working up the material which is continually being accumulated.

The Need for the Systematic Collection of Data.

The first task—that of collecting new information—is no small one. In many cases it must be undertaken on a scale that can be financed only by Governments. The Ordnance and Geological Surveys of our own and other countries are examples of Government departments carrying on this work. We need more of them. The Presidents of the Botanical and Anthropological Sections are, I understand, calling the attention of the Association to the urgent necessity for complete Botanical and Anthropological Surveys of the kingdom. All geographers will warmly support their appeal, for the material which would be collected through such surveys is essential to our geographical investigations.

Another urgent need is a Hydrographical Department, which would co-operate with Dr. Mill's rainfall organisation. It would be one of the tasks of this department to extend and co-ordinate the observations on river and lake discharge, which are so important from an economic or health point of view that various public bodies have had to make such investigations for the drainage areas which they control. Such research work as that done by Dr. Strahan for the Exe and Medway would be of the greatest value to such a department, which ought to prepare a map showing all existing water-rights, public and private. We shall see how serious the absence of such a department is if we consider how our water-supply is limited, and how much of it is not used to the best advantage. We must know its average quantity and the extreme variations of supply. We must also know what water is already assigned to the uses of persons and corporations, and what water is still available. We shall have to differentiate between water for the personal use of man and animals, and water for industrial purposes. The actualities and the potentialities can be ascertained and should be recorded and mapped.

The Need for the Application of Geographical Methods to Already Collected Data.

In the second direction of research—that of treating from the geographical standpoint the data accumulated, whether by Government departments or by private initiative—work has as yet hardly been begun.

The topographical work of the Ordnance Survey is the basis of all geographical work in our country. The Survey has issued many excellent maps, none more so than the recently published half-inch contoured and hill-shaded maps with colours 'in layers.' Its maps are not all above criticism; for instance, few can be obtained for the whole kingdom having precisely the same symbols. It has not undertaken some of the work that should have been done by a national cartographic service—for instance, the lake survey. Nor has it yet done what the Geological Survey has done—published descriptive accounts of the facts represented on each sheet of the map. From every point of view these are great defects; but in making these criticisms we must not forget (i) that the Treasury is not always willing to find the necessary money, and (ii) that the Ordnance

Survey was primarily made for military purposes, and that the latest map it has issued has been prepared for military reasons. It has been carried out by men who were soldiers first and topographers after, and did not necessarily possess geographical interests.

The ideal geographical map, with its accompanying geographical memoir, can be produced only by those who have had a geographical training. Dr. Mill, in the monograph already referred to, has shown us how to prepare systematised descriptions of the one-inch map sheets issued by the Ordnance Survey. The preparation of such monographs would seem to fall within the province of the Ordnance Survey. If this is impossible, the American plan might be adopted. There the Geological Survey, which is also a topographical one, is glad to obtain the services of professors and lecturers who are willing to undertake work in the field during vacations. It should not be difficult to arrange similar co-operation between the Universities and the Ordnance Survey in this country. At present the Schools of Geography at Oxford and at the London School of Economics are the only University departments which have paid attention to the preparation of such monographs, but other Universities will probably fall into line. Both the Universities and the Ordnance Survey would gain by such co-operation. The chief obstacle is the expense of publication. This might reasonably be made a charge on the Ordnance Survey, on condition that each monograph published were approved by a small committee on which both the Universities and the Ordnance Survey were represented.

The Geological Survey has in recent years issued better and cheaper one-inch maps, and more attention has been given to morphological conditions in the accompanying monographs; but it is necessary to protest against the very high prices which are now being asked for the older hand-coloured maps. The new quarter-inch map is a great improvement on the old one, but we want 'drift' as well as 'solid' editions of all the sheets. The geographer wants even more than these a map showing the quality of the solid rock, and not merely its age. He has long been asking for a map which would indicate the distribution of clay, limestone, sandstone, &c., and when it is prepared on the quarter-inch, or better on the half-inch, scale the study of geomorphology and of geography will receive a very great stimulus and assistance.

The information which many other Government departments are accumulating would also become much more valuable if it were discussed geographically. Much excellent geographical work is done by the Admiralty and the War Office. The Meteorological Office collects statistics of the weather conditions from a limited number of stations; but its work is supplemented by private societies which are not well enough off to discuss the observations they publish with the detail which these observations deserve. The Board of Agriculture and Fisheries has detailed statistical information as to crops and livestock for the geographer to work up. From the Board of Trade he would obtain industrial and commercial data, and from the Local Government Board vital and other demographic statistics. At present most of the information of these departments is only published in statistical tables.

Statistics are all very well, but they are usually published in a tabular form, which is the least intelligible of all. Statistics should be mapped and not merely be set out in columns of figures. Many dull Blue Books would be more interesting and more widely used if their facts were properly mapped. I say *properly* mapped because most examples of so-called statistical maps are merely crude diagrams and are often actually misleading. It requires a knowledge of geography in addition to an understanding of statistical methods to prepare intelligible statistical maps. If Mr. Bosse's maps of the population of England and Wales in Bartholomew's Survey Atlas are compared with the ordinary ones, the difference between a geographical map and a cartographic diagram will be easily appreciated.

The coming census, and to a certain extent the census of production, and probably the new land valuation, will give more valuable raw material for geographical treatment. If these are published merely in tabular form they will not be studied by any but a few experts. Give a geographer with a proper staff the task of mapping them in a truly geographical way and they will be eagerly examined even by the man in the street, who cannot fail to learn from them. The representation of the true state of the country in a clear, graphic, and intelligible form is a patriotic piece of work which the Government should

undertake. It would add relatively little to the cost of the census and it would infinitely increase its value.

The Need of Recognising the Geographical Factor in Imperial Problems.

With such quantitative information geographically treated, and with a fuller analysis of the major natural regions, it ought to be possible to go a step further and to attempt to map the economic value of different regions at the present day. Such maps would necessarily be only approximations at first. Out of them might grow other maps prophetic of economic possibilities. Prophecy in the scientific sense is an important outcome of geographical as well as of other scientific research. The test of geographical laws as of others is the pragmatic one. Prophecy is commonly but unduly derided. Mendelyeff's period law involved prophecies which have been splendidly verified. We no longer sneer at the weather prophet. Efficient action is based on knowledge of cause and consequence, and proves that a true forecast of the various factors has been made. Is it too much to look forward to the time when the geographical prospector, the geographer who can estimate potential geographical values, will be as common as and more reliable than the mining prospector?

The day will undoubtedly come when every Government will have its Geographical-Statistical Department dealing with its own and other countries—an Information Bureau for the administration corresponding to the Department of Special Inquiries at the Board of Education. At present there is no geographical staff to deal geographically with economic matters or with administrative matters. Yet the recognition of and proper estimation of the geographical factor is going to be more and more important as the uttermost ends of the Earth are bound together by visible steel lines and steel vessels or invisible impulses which require no artificial path or vessel as their vehicle.

The development of geographical research along these lines in our own country could give us an Intelligence Department of the kind, which is much needed. If this were also done by other States within the Empire, an Imperial Intelligence Department would gradually develop. Thinking in continents, to borrow an apt phrase of Mr. Mackinder's, might then become part of the necessary equipment of a statesman instead of merely an after-dinner aspiration. The country which first gives this training to its statesmen will have an immeasurable advantage in the struggle for existence.

The Need for the Adequate Endowment of Geography at the Universities.

Our universities will naturally be the places where the men fit to constitute such an Intelligence Department will be trained. It is encouraging, therefore, to see that they are taking up a new attitude towards geography, and that the Civil Service Commissioners, by making it a subject for the highest Civil Service examinations, are doing much to strengthen the hands of the universities. When the British Association last met in Sheffield geography was the most despised of school subjects, and it was quite unknown in the universities. It owed its first recognition as a subject of university status to the stimulus and generous financial support of the Royal Geographical Society and the brilliant teaching of Mr. Mackinder at Oxford. Ten years ago Schools of Geography were struggling into existence at Oxford and Cambridge, under the auspices of the Royal Geographical Society. A single decade has seen the example of Oxford and Cambridge followed by nearly every university in Great Britain, the University of Sheffield among them. In Dr. Rudmose Brown it has secured a scientifically trained traveller and explorer of exceptionally wide experience, who will doubtless build up a Department of Geography worthy of this great industrial capital. The difficulty, however, in all universities is to find the funds necessary for the endowment, equipment, and working expenses of a Geographical Department of the first rank. Such a department requires expensive instruments and apparatus, and, since the geographer has to take the whole World as his subject, it must spend largely on collecting, storing, and utilising raw material of the kind I have spoken of. Moreover, a professor of geography should have seen much of the World before he is appointed, and it ought to be an important part of his professional duties to travel frequently and far. I have never been able to settle to my own satisfaction the maximum income which a department

of geography might usefully spend, but I have had considerable experience of working a department the income of which was not very far above the minimum. Until now the Oxford School of Geography has been obliged to content itself with three rooms and to make these suffice not merely for lecture-rooms and laboratories, but also for housing its large and valuable collection of maps and other materials. This collection is far beyond anything which any other university in this country possesses, but it shrinks into insignificance beside that of a rich and adequately supported Geographical Department like that of the University of Berlin. This fortunate department has an income of about 6,000*l*. a year and an institute built specially for its requirements at a cost of over 150,000*l*., excluding the site. In Oxford we are most grateful to the generosity of Mr. Bailey, of Johannesburg, which will enable the School of Geography to add to its accommodation by renting for five years a private house, in which there will temporarily be room for our students and for our collections, especially those relating to the Geography of the Empire. But even then we can never hope to do what we might if we had a building specially designed for geographical teaching and research. Again, Lord Brassey and Mr. Douglas Freshfield, a former President of this Section, have each generously offered 500*l*. towards the endowment of a professorship if other support is forthcoming. All this is matter for congratulation, but I need hardly point out that a professor with only a precarious working income for his department is a person in a far from enviable position. There is at present no permanent working income guaranteed to any Geographical Department in the country, and so long as this is the case the work of all these departments will be hampered and the training of a succession of competent men retarded. I do not think that I can conclude this brief address better than by appealing to those princes of industry who have made this great city of Sheffield what it is to provide for the Geographical Department of the University on a scale which shall make it at once a model and a stimulus to every other university in the country and to all benefactors of universities.

The following Papers were then read :—

1. *The Origin of some of the more Characteristic Features of the Topography of Northern Nigeria. By* Dr. J. D. Falconer, *M.A., F.R.G.S.*

The Protectorate of Northern Nigeria comprises an area of about 255,700 square miles, the greater part of which lies between Lake Chad and the confluence of the Rivers Niger and Benue. The hydrographical centre of the Protectorate is the Bauchi plateau, which rises to a height of 4,000 to 5,000 feet above sea-level. The rivers belong to two great hydrographical systems, the Niger-Benue system and the Chad or desert system. The watersheds are lofty plains characterised by a matured topography, while the more prominent ranges of hills exert only a very secondary influence on the drainage system. The rivers in their upper and middle courses flow over open plains whose surface is diversified by numerous isolated granite domes, turtlebacks, and groups of rounded hills (inselberge). In their lower courses, on the other hand, they frequently flow in deep and trench-like valleys, bounded on either side by ranges of flat-topped hills. These plateau-like masses and tabular and conical hills have invariably been carved out of horizontal sedimentary rocks, while the isolated domes and turtlebacks of the upper plains afford clear evidence of a crystalline floor.

The peculiar character of the river valleys is entirely due to the recent origin of the whole river-system. It is believed that in late Tertiary times the surface of the Protectorate was for the most part reduced to low relief, and that the plains of Hausaland were continuous with the plains of Borgu and Ilorin across the Niger valley. The crystalline plains with their domes and inselberge, as well as the sedimentary plains with their flat-topped and conical hills, are to be regarded as a final product of the subaerial denudation of a land surface exposed to alternations of periods of erosion and periods of intense weathering of the rocks *in situ*. Late Pliocene or early Pleistocene crustal movements brought about the irregular elevation of this levelled surface into elongated arches and troughs along axes which run approximately N.N.W.—S.S.E. and W.S.W.—

E.N.E. The summits of the arches form the present watersheds, while the floors of the troughs are occupied by the present trunk streams. The effect of the interference of the two sets of arches, of their gradual and unequal elevation from point to point, and of the geological structure of the country can be readily recognised in the principal river valleys. The intersection of the two central arches was marked by the differential elevation of the Bauchi plateau and the Nassarawa table-land and the lagging behind of the middle Benue valley. The valleys of the upper Benue and of the middle Gongola are more ancient than the Niger valley, and appear to be relics of an earlier hydrographical system. The presence of swampy and lacustrine conditions in Bornu dates from a period preceding the movement of elevation. Lake Chad, as we know it, owes its origin indirectly to its position in a trough between two axes of elevation, and more directly to the recent presence of arid conditions in the Sudan.

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2. *The Exploration of Prince Charles Foreland, Spitsbergen, during* 1906, 1907, *and* 1909. *By* WILLIAM S. BRUCE, *LL.D., F.R.S.E.*

This communication was a result of explorations carried on by three Scottish expeditions during the summers of 1906, 1907, and 1909. A brief account having previously been given of the work during the first two years, an account of the third summer's work was mainly dwelt upon. In 1906 Dr. Bruce was accompanied by two assistants and was largely equipped by H.S.H. the Prince of Monaco, who also took the party from and back to Scotland on board his yacht *Princesse Alice*, landing them on the north end of the east coast south of Point Carmichael. In 1907 Dr. Bruce chartered the steamer *Phœnix*, which took his party of three and himself from Tromsö to Prince Charles Foreland and landed them twelve miles from the south end of the west coast at north end of Edinburgh Isles. The party returned from the Foreland in the walrus-sloop *Johannes Bache*. In 1909 the trawler *Conqueror*, of Leith, was chartered, the fish-hold being converted into a cabin for officers and scientific staff, and the after-quarters and foc's'le being reserved for petty officers and crew. There were nineteen all told, including the scientific staff of seven, besides Dr. Bruce. Captain Napier was master of the ship, now transformed into the yacht *Conqueror*. The following are the scientific people who have accompanied Dr. Bruce : Mr. Ernest A. Miller, in 1906; Mr. J. Victor Burn Murdoch, F.G.S., and Mr. Stewart Ross, M.A., in 1907; and Mr. John Mathieson (H.M. Ordnance Survey), Mr. R. N. Rudmose Brown, D.Sc., Mr. J. Victor Burn Murdoch, F.G.S., Mr. Harry Hannay, Mr. Ernest Miller, the late Mr. Angus Peach, B.Sc., and Mr. Alistair Geddes, in 1909. Piper Gilbert Kerr, formerly piper to the *Scotia*, accompanied all three expeditions.

The chief object of the expedition was to make a detailed map of Prince Charles Foreland. The map is a continuation of similar work carried on by the Prince of Monaco on the mainland of Spitsbergen and by Norwegians under his direction. The scale is 1 : 126,720=2 miles to an inch. The heights on the land are given in feet; the depths of the sea in fathoms. The island is about fifty-four miles long and from three to seven and a half miles broad, having an average width of five miles; the area is about 262 square miles. An almost continuous mountain chain occupies the northern two-thirds of the island. At the south end is a hilly portion, the 'Ross Heights,' separated from the northern chain by an extensive low-lying part now called the 'Foreland Laichs.' The northern mountain chain is now named the 'Northern Grampians,' and in its central part has hills rising to a height of over three thousand feet. The northernmost of these is Mount Monaco (3,800 feet) and the southernmost is Mount Jessie (3,300 feet). They are magnificent, precipitous, sharply peaked mountains with precipices and gullies to the west, while they are heavily glaciated to the east with a large and almost continuous ice-sheet, which is fed from glaciers arising in the first place from the very summits and highest ridges.

A considerable number of soundings were taken in Foul Sound, demonstrating a bar towards the northern end over which vessels drawing more than twelve or fifteen feet have difficulty in finding a passage. In the south end of Foul Sound depths of considerably over a hundred fathoms were obtained, rapidly coming up to three or four fathoms near Ferrier Haven.

Geologically, the island is composed of hard graywackès and schists, probably of the Hekla Hook series; at the west end of Glen Mackenzie very coarse conglomerates forming the North and South Sutors cccur with sandstone slabs resembling Caithness flags further to the west along the shore. On the east coast, fringing the low land which surrounds almost the whole island for a mile or more inland, are to be found tertiary beds containing plant remains. These occur to the south of Point Carmichael and at Ferrier Haven.

The flora is similar to that of the mainland of Spitsbergen.

The fauna is also similar to the mainland, but Dr. Bruce added a new record not only for the Foreland, but for European Arctic regions, in finding the adult and fledglings of the sanderling there. The capture of the sabine gull and the recording of great northern diver and razor-bill are also noteworthy. Much yet remains to be worked up regarding the micro-fauna.

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3. *Plans for a Second Scottish National Antarctic Expedition*, 1911. *By* William S. Bruce, *LL.D., F.R.S.E.*

It is hoped that this expedition will leave Scotland about May 1, 1911, and reach Buenos Aires about June 20. From Buenos Aires a departure will be made about July 1, and a zig-zag course steered between 40° and 50° for the purpose of broadly completing the bathymetrical survey of the South Atlantic Ocean begun by the *Scotia* in 1902-04. Cape Town should be reached on September 1. At Cape Town the ship will coal and refit, and a course will be steered for the Sandwich Group, where it is hoped funds will allow another vessel to meet her, carrying equipment, coal, and fresh food from Buenos Aires. Further soundings will be made between Cape Town and Sandwich Group, especially to try and prove the hypothetical 'Rise' joining the Sandwich Group and Bouvet Island, as well as the 'Scotia Rise,' discovered by the Scottish Expedition, 1904. From the Sandwich Group the expedition will steer for Coats Land or some place with suitable anchorage and landing in the vicinity of Coats Land. A party of ten or twelve persons will be landed here and a house erected. As there appeared to be no suitable landing-place along the 150 miles of Coats Land discovered by the Scottish Expedition in 1904, the expedition may have to go a little further west or east, possibly as far east as Cape Ann, Enderby Land. The ship will thereafter proceed to Melbourne by a route in as high a latitude as possible, taking soundings and carrying on deep-sea research, having as a special objective the determination of former continental connections. The ship will winter at Melbourne, carrying out such work as funds will allow and time will permit by means of one or more short cruises to the south. Co-operation with Australian and New Zealand Governments and scientific societies in any special work which they would wish to have accomplished in these seas would be welcomed. In the spring the ship will push southward to McMurdo Strait, Victoria Land, in order to send a sledge party southward with supplies for another party, which, under my leadership, will be crossing over the Antarctic Continent by way of the South Pole from Coats Land. The meeting of the trans-continental party and the relief party will likely be in the vicinity of the Beardmore Glacier. The combined parties will then return to the ship and sail for New Zealand. The Scottish Expedition will not make any special investigations in the region of McMurdo Strait, because since the publication of these plans in April 1908 and April 1909 Captain Scott has chosen this region as his special sphere of work. From New Zealand the ship will proceed across the Pacific Ocean to Magellan Straits or the Falklands, and carry on such oceanographical research as is possible in as high a southern latitude as the winter season will permit. In the spring the expedition will proceed southward in the Weddell Sea to relieve the wintering party, which will now have spent two years there. This party will devote special attention to the survey of the coastline of Antarctica both to the east and west of the station. Complete meteorological, magnetic, and other physical and biological outfit will be provided, and it is hoped that arrangements will be made to co-operate with Meteorological Stations at Scotia Bay, South Georgia, Cape Pembroke, and elsewhere. The total cost of the expedition will be about 50,000*l*.

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4. *The Voyage of the 'Nimrod' from Sydney to Monte Video, May 8 to July 7, 1909. By* J. K. Davis.

Acting under instructions from Sir E. Shackleton an attempt was to be made to locate the positions of some charted islands marked 'doubtful,' viz. : (1) Royal Company Islands, (2) Emerald Island, (3) Nimrod Islands, and (4) Dougherty Island. In the event of being able to find any of these 'doubtful' islands, we were to land (if possible), obtain their precise positions and main features, &c. In the event of no land being visible at or near the charted position, deep-sea soundings were to be taken and vicinity searched.

Meteorological observations were to be taken at intervals of two hours during the voyage, and these are of some interest, as ships do not usually traverse these latitudes in the months of May and June.

We visited Macquarie Island, and obtained numerous specimens (skins, skeletons, mosses, rocks, &c.).

The question how the islands (marked 'doubtful') came to be placed on the chart, the precautions taken to secure reliable results in observations for latitude and longitude during the voyage, and the weather conditions, currents, soundings, &c., were discussed.

Narrative of the voyage :—

May 8. Sailed from Sydney.
May 18. Sailed over charted position of Royal Company Islands. No land visible.
May 26. Anchored off Macquarie Island. What we found on the island.
May 30. Left Macquarie Island.
June 9. Search for Nimrod Islands.
June 17. Search for Dougherty Island. Ice met with.
June 27. Sighted Diego Ramirez Island at a distance of 14 miles.
July 7. Arrived at Monte Video.

Results of the voyage and reports furnished by navigators since the islands were first charted were considered.

FRIDAY, SEPTEMBER 2.

Joint Meeting with Section C.

The following Papers were read :—

1. *The Geology of Sheffield. By* Cosmo Johns.

2. *The Metallurgical Industries in relation to the Rocks of the District. By* A. McWilliam, *A.R.S.M., M.Met.*

Sheffield is situated on the outcrop of the Coal Measures, which consist of alternating sandstones and shales, with beds of coal, clay ironstone, and fireclay. The district was in ancient times thickly wooded, affording supplies of the then principal metallurgical fuel, charcoal. The raw fuel of to-day is coal, and the enormous influence of this source of practically all our power, high temperatures, reducing agent, and artificial light is so obvious that it need only be mentioned. Different beds of this coal are suitable for making into the various kinds of coke required for crucible, cupola, and blast-furnace work. There is coal that is suitable for steam-raising and for making into producer gas for use in the great open-hearth and other gas-fired furnaces, and there is even a bed that fulfils the very exacting needs of the old cementation furnace. With regard to coal the most striking development since the last visit of the Association is the establishment of a line of collieries down the outcrop of the Permian rocks to the east, where the well-known beds of coal were found at reasonable depths. Recent

developments even within the last two or three years have made the district one of the richest in the kingdom with regard to coal supply. The clay ironstone, ferrous carbonate with clay, yields an excellent pig iron, containing about 0·6 per cent. phosphorus, and suitable for making into castings and for the manufacture of the best qualities of wrought iron for use as such. This ore is the source of the famous Yorkshire iron, still made near Leeds, though in diminishing quantities. The great bulk of the ironstone now used is the cheaper variety from Northampton, Leicester, and Lincoln, and consists of brown iron ore, hydrated ferric oxide, yielding pig irons containing about 1¼ per cent. of phosphorus. These are suitable for manufacturing cast-iron castings and ordinary wrought iron and for making into basic steel, the refractory dolomite necessary for lining the vessel or making the hearth in which the steel is made being procured from the magnesian limestone to the east. These pig irons are not suitable for making into the highest qualities of Sheffield's special steels, so hematite pig-irons, from the hematite ores of Lancashire, Cumberland, and Spain, are imported for making into acid Bessemer or acid open-hearth steel, that is, steel made in an acid- or silica-lined vessel or hearth, and that can thus be finished in contact with an acid slag. The best qualities of Swedish wrought irons are also imported for making into cutlery, edge tools, general cutting tools for engineers, &c. As refractory materials for these processes, and even for the roofs of the basic furnaces, much acid material of great purity is required. Some of the Coal Measure sandstones consist of particles of quartz that have been cemented by silica, so that the whole rock very often consists of 98 per cent. SiO_2. This rock, called ganister, is mined round Oughtibridge and made into refractory silica bricks for withstanding the highest furnace temperatures. A similar firestone is used for building the walls between the crucible holes and for other purposes, and ground ganister, mixed with a little fireclay and water, is rammed round wooden moulds to form the crucible melting holes and also the linings of Bessemer converters. Fireclay is also abundant, providing the firebricks used for the less highly tried portions of the furnaces. Some of the carboniferous sandstones yield splendid grindstones, and building stones are abundant and at high levels, whilst there are deposits that are of the composition necessary for making ordinary bricks without any additions. The inexhaustible Derbyshire limestone is available as a flux, and the fact that lead mining in the mountain limestone was once a great industry has an important bearing on the manufacture of basic steel, for the great heaps of gangue left by the miners are being worked over for fluorspar, which is used to help in desulphurising the metal. Barytes is won at the same time, and though mainly used as the most permanent white basis of photographic papers and for mixing with white lead, some of it may be converted into $BaCl_2$, which is brought to high temperatures by electrical means for heating high-speed steels for hardening purposes. The millstone grit, once so famous for its use as millstones for grinding corn and for erecting buildings to last for aye, is now superseded, for the former by iron rolls, and as it is too hard to work for present-day building requirements, it is mainly left to look grim and grand in the scenery, though recently it has been much used in building the new great dams and helping to add the only feature our beautiful district lacked, extensive sheets of water. Ganister has been mentioned, a sandstone in which the particles of quartz are cemented by quartz. To the east of Sheffield, in the Upper Permian and perhaps Lower Triassic beds, as, for example, near Worksop, there are extensive deposits of a natural red moulding-sand of the best quality, in which each rounded particle of quartz is roughened by a coating of reddish brown oxide of iron, and the whole deposit contains the right admixture of clay to give the necessary compromise between binding quality on the one hand and porosity on the other required in a moulding sand for general foundry-work.

Sheffield is therefore situated in the midst of an abundance of flux for dealing with impurities, of fuel for power and for attaining the high temperatures required in the manufacture of iron and steel, and of the best of refractory materials for withstanding these high temperatures; and when materials at hand do not satisfy the severe requirements of the special trades others are freely imported, as in the case of hematite pig-irons and Swedish and other wrought irons for making into the highest qualities of special steels.

3. *The Humber during the Human Period.* By T. SHEPPARD, *F.G.S.*

Mr. Sheppard has made a collection of the various published and manuscript charts and maps of East Yorkshire dating from the time of Henry VIII. to date. A great number of these are of particular interest, as they illustrate the extraordinary changes that have taken place in the south-east corner of Yorkshire. Probably no district in the British Islands illustrates so well recent geographical changes as does South-east Yorkshire.

Between Bridlington and Spurn Point, a distance of some thirty miles, the land has been worn away at a rate varying from a few feet to over twenty feet per annum. Careful measurements show that an average of seven feet per annum has been washed away along this coast line. This estimate is confirmed by historical data. Entire villages have been swept away; in recent years great areas of land have been swamped; whilst, on the other hand, meres and marshes in Holderness have been artificially drained and are now dry land.

Spurn Point is the only part of the Holderness coast that has grown, and measurements of this are given showing its progress from 1428. It was also pointed out that at different periods in its history the tongue of sand had been severed and islands were formed. Upon some of these the author suggested the towns of Ravenser and Ravenser Odd existed in mediæval times but have now disappeared. After dealing with the lost villages and towns of the coast and the Humber the author described in detail the growth of new land within the estuary, particularly at Sunk Island, Reads Island, and Broomfleet Island. Photographs of the various charts were thrown upon the screen, some of which were exceedingly scarce or had been previously entirely unknown. One of them, *circa* Henry VIII., showed an island to the east of Spurn Point.

The following plans were exhibited in illustration of the paper: MS., *temp.* Henry VIII.; Speed, 1610; Dutch map, early seventeenth century; Blome, early seventeenth century; Collins, 1684; Morden, 1722; Moll, 1724; Chart, 1725; Scott, 1734; Bowen, 1750; Jeffreys, 1772; Kitchen, 1774; Tuke, 1786; Cary, 1805; Directory, 1838; Boyle, 1889.

An interesting series of plans and views of Hull illustrated in the way in which that town was encroaching upon the Humber estuary.

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4. *Matavanu, a New Volcano in Savaii (German Samoa).* By TEMPEST ANDERSON, *M.D., D.Sc., F.G.S.*

Though not the seat of government, Savaii is the largest of the Samoan Islands in the Central Pacific Ocean. It has a backbone of volcanic mountains, some of which rise to a height of over 4,000 feet; most of them are extinct or dormant, but there have been several small eruptions within the last two hundred years, and one as lately as 1902.

The volcano of Matavanu was formed in 1905 to the north of the main ridge, and near the centre of the island. The early part of the eruption was characterised by explosions, and the ejecta were mainly solid, but later on an enormous quantity of very fluid basic lava has been discharged. This has flowed by a sinuous course of about ten miles into the sea, devastated some of the most fertile land in the island, and covered it up with lava fields probably not less than twenty square miles in area.

The crater contains a lake, or rather river, of molten lava so fluid that it rises in incandescent fountains, beats in waves on the walls, and rushes with great velocity down into a gulf or tunnel at one end of the crater. The lava, still liquid, runs into a passage, or perhaps system of passages, under the surface of the lava field, its course being traceable by a line of large fumaroles, till, still in a fluid condition, it reaches the sea, into which it flows with energetic explosions and the discharge of large volumes of steam, black sand, and fragments of lava. Where the action is less violent a structure resembling that of some varieties of pillow lava is produced.

Photographs were shown on the screen illustrating the crater, the lava fields, with their subsidences and tunnels, the explosions, as well as others which enabled a comparison to be made between the devastated and untouched parts of the island.

See *Q. J. Geol.*, November 1910; *Nature*, November 17, 1910.

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5. *Present Trias Conditions in Australia.* By Rev. E. C. Spicer, *M.A., F.G.S.*

Triassic conditions in England resulted in (1) the jagged outline of the peaks visible above the 'buried landscape' of Charnwood Forest which were thus modified during their exposure in Trias times; (2) the formation of the 'Bunter pebble bed'; (3) the thick deposits of wind-bedded Trias sandstones; (4) the Keuper marls; (5) the salt deposits; (6) the poor fauna and flora; (7) footprints and burst viscid bubbles ('raindrops').

Flinders Range in South Australia is modified into rounded outlines in the south, where there is a fair amount of regular rainfall. In the northern part of the range, beyond the influence of the southern cyclonic system, the range becomes (1) *jagged* in character.

(2) During some years there is no rain at all. When a drought breaks up there is usually a 'deluge' of two or three inches, sometimes falling in twenty-four hours, accompanied by heavy thunder. The only outlet from the range-mass is through gorges five miles apart opening on to the Great Western Plain. A great wall of water rushes furiously through these gorges, pushing a mass of *boulders* and *gravel* bodily downwards, gradually wearing the hard materials down and spreading them in great sheets over the plain.

(3) In the long dry summers and in drought seasons the Great Western Plain is covered by a mass of moving *sand*, driven in great clouds by the rare high winds and constantly drifting over the plain.

(4) Around Lake Torrens and inland the surface is more compact and of a *marly* character.

(5) Lake Torrens is flooded during the rain-storm periods. As the lake water evaporates the marshy border dries up, and there are great areas of coarsely crystallised *salt*.

(6) The plain below Flinders Range is almost destitute of life, with the exception of a few *birds* and *reptiles*. All the animals that cannot escape to trees are drowned when the floods occur.

(7) The drying muds receive the impression of *emu tracks;* the drifting sands blow over these and preserve them, while the decaying drifted vegetation produces *gas bubbles* in the viscid mud, which is also covered by drifting sand.

Thus the northern part of the Flinders Range area and the Great Western Plain region extending to Lake Torrens reproduce Trias conditions at the present time.

The following Paper was read in Section E :—

Notes on a Journey through South America from Bogota to Manâos viâ the River Uaupés. By Hamilton Rice, *B.A., M.D.*

The author spoke of the march from Bogota to Villa vicencio by passage of the Andes and across the 'llanos' to San Martin, the cattle centre of S.E. Columbia and last outpost of municipal control.

The 'tierra caliente' and beginning of the densely forested Amazonian area marked by the watershed of the Meta and Guaviare rivers, big western tributaries of the Orinoco, just to the south of which region the sources of the Uaupés originate.

The river's extent and geological character of the country through which it flows.—In the western portion the rock masses and hills are of lacolithic structure, as evidenced by their scoriaceous and pyroclastic appearance, which attests a very rapid cooling from the original frothy and viscid condition. In the eastern part of its course the rocks forming its rapids and composing the discrete dome shaped and sugar-loaf forms of hills are granitic in character, and the river banks are formed of coarse or fine sand instead of the soft unctuous-like mottled-clay found everywhere above.

From any eyrie where far-reaching areas may be discerned the terrain presents a surface of undulating or crumpled unevenness, suggestive of a process of uplift having ensued in conjunction with, or as complementary to, the violent volcanic cataclysms of a former period.

The aborigines, or so-called Indians, inhabiting its banks, of Tupi-Guarani

stock. 'Mansos' or peaceable tribes, and 'bravos' or wild ones. Cubbeos, Quenanas, Tarianos, and Tucanos, the four tribes of the main river. Some anthropological and ethnological considerations of the respective tribes. Diversity of size and characterised by types varying from Caucasian to Mongoloid.

A religion in which a single Supreme Being is worshipped and invested with all the awe-inspiring and terrifying attributes that such a conception would seem most likely to engender in the thoughts of a people whose mentality could not fail to be influenced by the eeriness and mystery of the stupendous forest, with its hideous and repulsive serpents and deep gloom, the terrific thunderstorms the country is subject to, and the river, treacherous of navigation and full of roaring foaming rapids, such an environment as would, through fear, inspire morbid emotion and superstition. No belief of a future existence. To pay homage to or appease the anger of this Being consists of a ritual of extraordinary and weird rites, but the ceremonies degenerate into orgies of cachiré drinking and insensate revelry, and they seem to have lost their power of appeal to the psychical side of the people.

Live under primitive communal conditions, existing by hunting, fishing, and practising agriculture to a limited extent. All practice monogamy except the chiefs or tuchánas, whose rule is absolute and hereditary in the male line.

Diseases.—The people's immunity from certain forms and marked susceptibility to others.

The 'caucheris' or traders and the rubber industry as carried on in this region.

Data from which the map of the river was made.

MONDAY, SEPTEMBER 5.

The following Papers and Report were read:—

1. *Cotton Growing within the British Empire.* *By* J. Howard Reed, *F.R.G.S.*

The cotton industry of Lancashire, which ranks next to agriculture in importance, employs close upon 500,000 workers and gives sustenance to several millions of people, depends entirely upon an ample supply of raw cotton-fibre, imported from thousands of miles across the seas, not one ounce of which can be grown at home. A shortage in the supply of raw cotton during recent years has caused not a little trouble and distress, and threatens more serious disturbance in the future. The shortage of cotton has been brought about by the greatly increased demands for raw fibre by the mills of Europe, and more especially by the vast development in the manufacture of cotton goods in the United States. Though the quantity of raw cotton used in Lancashire to-day is only a trifle more than was the case twenty years ago, during the same period the weight of fibre used on the Continent has very nearly doubled, and the total is now more than twice that of the British figure. The demand of the American mills has increased at an even greater rate than has that of Europe, and is now nearly double the British demand and nearly equal to that of the whole of the Continental countries.

Year by year we are gradually approaching a very serious crisis, as the shortage of cotton is regular and progressive, and unless supplies of raw fibre are obtained from other fields than those of America the Lancashire industry will not only gradually languish and decay, but will completely perish. For this reason it has become all-important that the industry of cotton growing in British colonies should be fostered and developed, and if the effort is not abundantly successful within a few years the great staple trade of Lancashire is doomed. This is a sweeping statement, but it is none the less true, although the people most interested even now do not seem fully to realise the position. For several years the British Cotton Growing Association have energetically devoted themselves to the solution of the problem, with some measure of success, although they have been tardily and inadequately supported with the financial aid which the great work needs. The countries of Egypt and India up to now have been

the only substantial sources of supply which have supplemented the production of the American cotton-fields. Some measure of increase may be expected from these districts, but such expansion will be wholly inadequate to meet the increasing demands of the world. It is well known that, generally speaking, all countries within forty degrees north and south of the Equator are climatically capable of growing cotton, provided the soil is of average fertility and the rainfall sufficient. It will be at once seen that such a cotton-growing zone embraces the whole of the British colonies except Canada, Tasmania, and a portion of New Zealand. Consequently there should be no physical or geographical difficulty in obtaining ample supplies of cotton within the British Empire, provided the necessary stimulus, financial and otherwise, is applied. The island colonies of Cyprus, Malta, Mauritius, Seychelles, and Fiji, and portions of Australia, British Borneo, and the East Indian colonies each and all produce native cotton, and such production can doubtless be considerably increased and rendered available for export. In the West Indies the efforts of the British Cotton Growing Association have already succeeded in re-establishing the industry of cotton-growing, with much promise of success. The African colonies, more especially Uganda, Nyasaland, and Lagos, have conclusively shown that the 'Dark Continent' is destined to provide a very large share of the cotton fibre which is so essential for the commercial prosperity of the mother country and for the salvation of the great Lancashire industry. So far for the seven years during which the cotton-growing effort has been pushed and stimulated considerable success has been achieved, but what has been done only makes it clear that the efforts need to be continued with increasing energy. The increased production of cotton, due to the efforts of the British Cotton Growing Association, has been progressive from year to year, but the needs are so enormous and the work so colossal that the increased supplies obtained during seven years only reach about one-thirtieth of Lancashire's average yearly demand. Devotion, energy, persistence, and increased financial aid are urgently needed from all sources, whether they be private, commercial, or Governmental.

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2. *The Region of Lakes Albert and Edward and the Mountains of Ruwenzori.* *By* Major R. G. T. Bright, *C.M.G.*

The country described lies to the south-east of Lake Edward and close to the Uganda-German East Africa frontier. The name Albert Edward for Lake Edward used to cause confusion between it and Lake Albert. There was a also a large arm of Lake Edward which had no native name. Last year King Edward approved of Lake Albert Edward being known as Lake Edward and its north-easterly arm being named George after the Prince of Wales. Travellers and Government officials had at various times visited the greater portion of the country we passed through. Lake Edward occupies a depression from 1,000 to 2,000 feet below the plateau and is 3,000 feet above sea-level. At the southern end is a flat plain with a few acacia thorn and euphorbia trees dotted over it. Hundreds of antelope roam over the plain. The few inhabitants (Bakonjo) live close to or even on the waters of the lake, passing a curious existence and dwelling on rafts. The water is brackish and unpalatable. Near the northern shore is a group of small islands, one of which is densely populated. There is no room for cultivation, so its inhabitants live on fish and foodstuffs purchased from the natives on the mainland.

Kazinga Channel is a narrow strip of water from one-quarter to three-quarters of a mile in width. It connects Lake Edward and Lake George, which lie in open country. Its shores are swampy, especially where it is entered by the River Mubuku. The swamp on the north-east of the lake was generally full of elephant, and a large herd of buffalo roamed with them.

The Katwe salt lake is worked by the natives. The salt is prepared and then made up into loads wrapped round with banana leaves. In this form it is carried by men to the various native markets; it is not, however, fit for European consumption. The river Semliki flows out of the north end of Lake Edward along a broad shallow valley through the eastern extremity of the great Etuli forest of Equatorial Africa. The forest is often of the greatest density,

though not always tropical in character. It is dismal in the extreme and swarms with stinging ants and insects. The Semliki valley becomes an open grass plain near Lake Albert.

The huge ridge of Ruwenzori lies between the River Semliki and the plateau north of the Edward depression. It is some seventy miles in length and about thirty miles across in its widest part. Above the forest area, a little over 14,000 feet, are bare rocks, ice, and snow. Streams descend from the glaciers through deeply scoured valleys on the east and west. Some small lakes lie below the snow regions. The snow peaks of Ruwenzori are situated in an area of about fifty-five square miles in the central part of the mountains. They consist of three main groups, that reaching the greatest height being on the west. Peak Margherita, the summit of the range, is 16,794 feet in altitude. The snow line in the valleys comes as low as about 13,200 feet. It is but a few miles north of the equator.

Lake Albert bears a strong general resemblance to Lake Edward. Their widths are much the same, some thirty miles across, though the former is about 100 miles in length—double that of Lake Edward. The mountains on the west of the lake rise to an altitude of 7,000 feet and over, and in places fall sheer into the water, while on the opposite side is a similar escarpment which runs close to the lake. At the northern end this line of hills diverges eastwards, leaving a broad scrub-covered plain. Native market-places have been established at the Government stations, and there every morning a brisk trade is carried on in food-stuffs, &c.

There is iron ore in the highlands, which is smelted for the making of weapons and agricultural implements. An extraordinary absence of animal life is noticeable in the mountains; except in certain parts, which are visited by elephants in the wet seasons, the country is destitute of wild animals and birds. The lowlands, however, are rich in game. The lake swarms with hippopotamuses and crocodiles, more especially at the mouths of the small streams.

In the narrow strip of country between the Congo-Nile watershed and Lake Albert the inhabitants differ widely. Korovi appears to be the meeting-point of the Bantu and Nilotic peoples. The Balegga and Bavira are of Bantu origin and are closely allied. Northwards of Korovi the country is inhabited by the Lendu, a finer and a darker tribe than either the Balegga or Bavira. The Lendu are warlike and treacherous, and we had several men killed whilst in their country. The native kingdom of Ankoli, one of the three kingships in the neighbourhood of the lakes, may be said to stretch so far westwards as the shores of Lake Edward. Its population can be roughly classified as the Bahima, the aristocracy, and the Baëro, the cultivators and serfs. In Bunyoro, on the west of Lake Albert, the natives have a custom of extracting the four lower front teeth, which causes the upper teeth to grow forward. The Baamba live in the forest country on the west of Ruwenzori. Their villages are built on the tops of ridges, and a stout wooden stockade encircles them. The Baamba fear the pigmies; these little people neither cultivate the land nor do any cultivation. They do not even built huts. They prey on the crops of their larger neighbours, and in return do them service when fighting and hunting. The Batwa or Bambutu dwell in the forest on both sides of the River Semliki. They are pigmies, standing about four feet high. Though there are several different kinds of pigmies, they appear to have no tribal organisation.

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3. *Report on the Geodetic Arc in Africa.*—See Reports, p. 75.

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4. *Through the Heart of Asia from India to Siberia.* *By* Lieutenant P. T. Etherton, *F.R.G.S.*

The expedition from India through Gilgit, Hunza, across the Pamirs, and thence through Chinese Turkistan, Mongolia, and Siberia to the Trans-Siberian Railway was undertaken by Lieutenant Etherton, Indian Army, for the purpose of big-game shooting and the study of the larger fauna of Central Asia and

Mongolia. The distance covered totalled nearly four thousand miles, and lay over routes which to a great extent had never previously been traversed. The only persons who completed the whole of the journey were Lieutenant Etherton and his native orderly, a Garhwali from the Himalayas, the caravan men and followers being changed from time to time. The average strength of the caravan was ten men, but this was varied to meet circumstances. Lieutenant Etherton left Lansdowne in the Himalayas in March 1909 and travelled *viâ* Kashmir, the Gilgit Valley, and Hunza to the Pamirs, meeting with great difficulties on the way, owing to the road being blocked by snow and huge avalanches. On the Pamirs the expedition remained one month, camp being at an elevation of from 14,000 to 15,000 feet above sea-level. From the Pamirs Lieutenant Etherton proceeded by the Ili Su Pass (16,750 feet) to the little-known Yarkand River, and thence crossed into the Kulan Urgu Valley by a pass (17,400 feet) which had never previously been crossed by a white man. Here the expedition met with numerous difficulties owing to the mountainous nature of the country, one of the yaks being lost down a precipitous slope, falling over 1,500 feet. After that the greatest difficulty was experienced in crossing fords in the Kulan Urgu valley. Lieutenant Etherton arrived there in June, when the water is at its highest from the melting snow. The fords are extremely dangerous, yet twenty-six of them were crossed in one day. From the Kulan Urgu valley the expedition crossed by two high passes into the valley of the Asgar Sai, and down this to Yarkand, where it arrived in the middle of June after many adventures. Thence the journey was continued onward through Chinese Turkistan for several hundreds of miles to the Tian Shan Mountains, the central portion of the mountain system of Asia. Here three months were passed, during which Lieutenant Etherton visited and traversed the Great Yulduz valley, about which comparatively little is known since the Russian explorer Prejevalsky travelled through a part of it in 1873. In the Tian Shan the expedition was in the midst of the ibex and the Asiatic wapiti country, and some fine specimens of the latter were bagged. Thence the expedition crossed into the Ili valley and on to Kulja, a town of much political importance. From here Lieutenant Etherton struck through the Sairam Nor and Ebi Nor country and the mountains beyond to Chuguchak, a town in Western Mongolia. In this stage of the march difficulties were numberless, for the region is practically unknown, the people lawless, while the climate at this season (November and December) is noted for its severity. It was in the country bordering on that vast inland sea, the Ebi Nor, that the traveller first saw wild horses. He passed around the Kesil Bach Nor, in Mongolia, another inland sea. The expedition encountered strange nomad tribes of Kalmuks, Kazaks, Kirghiz, and Mongols, concerning whom many interesting notes were gathered. The expedition reached the foot of the Great Altai Mountains on the northern side of the Black Irtish valley at the end of December, with the thermometer at -35° and the whole country ice-bound. The Altai form the principal range in this part of Asia, their composition consisting largely of argillaceous schists, with granite in the higher parts, and alluvium and diluvium lower down. In this extensive chain is found a great variety of the larger fauna, including *Ovis Ammon,* the true Argali of the great Argali sheep of Central Asia, as well as the Altai wapiti, red bear of a species peculiar to the Altai, roe deer, and other animals. While in the Altai the expedition was caught in a blizzard, and practically the entire caravan was frost-bitten, including Lieutenant Etherton and his orderly. Thence ensued twelve fearful days of trekking to a small military post on the Siberian-Mongolian frontier, where medical assistance was available. The expedition arrived here on January 9, 1910, and a month later continued the journey for eight hundred miles through Siberia to the Trans-Siberian Railway, mostly by sledge. Lieutenant Etherton's trophies included ibex, the rare Asiatic wapiti stag, roe deer, *Ovis Karelini,* &c. He reached England in March 1910.

TUESDAY, SEPTEMBER 6.

The following Papers were read :—

1. *A New Globe Map of the World and a New Equal-scale Atlas.* *By* W. WILSON.

The use of the globe as an aid in teaching geography has largely disappeared owing to the high cost and cumbrous nature of the globes employed. The author overcomes this difficulty by mounting a special globe map on thin cardboard and cutting out the gores. The two ends of the map are joined at the equator by a clip; a spindle is introduced, and the tips of the gores are passed down over the ends of the spindle by means of holes punched at the ends of each gore where the poles would be, a metal clip at each end holding the tips in position and serving as a convenient means of handling the globe. The result is an instrument which can be used effectively in place of an ordinary globe. It can be made up or dismantled in a few seconds, studied as a flat map or as a globe, and packs readily, taking up no more space than an ordinary school book.

Several novelties have been introduced with a view to giving beginners a firm mental grasp of the world as a globe. The tropic and polar circles are deferred for later consideration. The world from the equator, 0°, to the pole, 90°, is divided into three belts of 30° each : a tropical belt, from 0° to 30°; a temperate, or rather intermediate belt, 30° to 60°; and a polar belt, or rather cap, extending from 60° to 90°. These form the primary divisions of latitude, and are indicated by heavier lines, preferably printed in colour. The series is easily remembered, 0°, 30°, 60°, 90°, and works in effectively with the value of a degree of longitude at each latitude :—

At 0°, 60 geog. miles.
At 30°, 52 „
At 60°, 30 „

These are readily remembered, and form a foundation for any further details regarding latitudes. The primary belts are subdivided for later teaching, each into three belts of 10°, with distinguishing names.

The longitudes are divided primarily into eight groups of 45° each, a group forming a gore. Each group of 45° is subdivided into three groups of 15°—one hour each, three hours to each gore. These have been found in practice the best working divisions of longitudes and are easily remembered. A few exercises will give the beginner a firm grasp of latitudes and longitudes, distances, and areas.

By these primary divisions the world is divided into forty-eight sections, each 45° E. and W. and 30° N. and S. Each section is treated as a straight-sided figure, so converting the globe into a polyhedron of forty-eight facets. All sections or facets in the north tropical belt are exactly alike. The sections in the south tropical belt are of the same figure, only inverted, making sixteen in all. The intermediate belt sections are narrower, east to west, than the tropical sections, but every section of the two belts is the same as every other section.

The polar belt, or rather cap, is a series of triangles which are more effectively dealt with when grouped two or more together, but each section is kept distinct. By this arrangement there are only three differing figures in the polyhedron, and each is characteristic of its belt. The error or distortion in each section is strictly limited, and once effectively demonstrated for any one of the three figures is immediately applicable to the remaining fifteen. The sections can be enlarged to any extent, forming an atlas on a simple equal scale that is readily grasped and is suited for many purposes besides elementary geography. A set of 'window' diagrams, each one combining a section of one belt on this plan and the same area as shown on Mercator, makes an instructive demonstration of the exaggeration necessary to Mercator, which is not usually clearly understood.

2. *The Andover Region: the Geographical Aspect of its Present Conditions.* *By* O. G. S. Crawford.

Introduction.—Reason for choice of title; the two points of view; evolution in time and distribution in space; a proposal to reconcile them.

1. *Physical Features.*—(*a*) Land forms; (*b*) drainage system; both the result of geological structure.

2. *Natural Vegetation.*—Gradual replacement by artificial vegetation; survivals of the old order; to grasp the significance of any epoch, past or present, the precise limits of forest, cultivation, and waste must be known and visualised.

3. *Industries.*—Outcome of the geology and vegetation; (*a*) agriculture, or artificial vegetation; (*b*) livestock; (*c*) building materials; (*d*) road materials.

4. *Settlements.*—Their distribution determined by need of sustenance for man and beast.

5. *Communications.*—Character directly influenced by physical features and vegetation.

Conclusion.—The reaction of man upon his natural surroundings.

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3. *A Regional Survey of Edinburgh—Sheet* 32. *By* James Cossar.

The region represented on Sheet 32 of the one-inch map of the Ordnance Survey of Scotland embraces practically the whole of Midlothian, about two-thirds of the county of Linlithgow, and about seventeen square miles of Fife. The most important physical feature is the range of the Pentland Hills, which rises a few miles to the south-west of Edinburgh, extends across the region for a distance of twelve miles into the adjoining county of Lanark, where it is cut off from the southern uplands by the valley of the Clyde. Besides exerting an important influence upon the climate, the vegetation, and industrial activities of the region, the Pentlands divide the low-lying area into two well-marked districts: to the east there extends a gently undulating plain, rising from the coast and only reaching an elevation of 500 feet at a distance of eight miles from the sea, traversed by the well-wooded and picturesque gorge of the River Esk, and gradually becoming merged in the lower slopes of the Pentlands and the Moorfoot Hills; to the north and north-west another plain, greater in extent but diversified by a number of hills and ridges, generally with an east-to-west direction—*e.g.*, Mons Hill, Arthur's Seat, Dalmahoy Hill. These hills and ridges are of volcanic origin, and their appearance at the surface is the result of the prolonged period of denudation that followed the Carboniferous Age, and especially during the glacial epoch, and have profoundly affected the historical and commercial relations of the region—*e.g.*, the building of the Forth Bridge. The passing of the ice-sheet across the region has exerted a profound influence not only upon the configuration, but also upon its economic development. As a result of the action of the ice great numbers of boulders were transported to the region, sometimes from a considerable distance; a remarkable example is in the Comiston sandpit near Edinburgh. Deposits of glacial sand and gravel are widespread and have frequently served to furnish a water-supply, as well as for building purposes. The deposits of boulder clay, sometimes attaining a depth of 100 feet, have exerted an important influence upon the fertility of the region, and have also given rise to the manufacture of bricks, tiles, and pottery—*e.g.*, at Portobello and at Bo'ness. The effect of the ice-sheet upon the topography is well seen in the crag and tail whereon the city of Edinburgh first took its rise and in the series of parallel ridges along which the new town has extended. The effect of the ice is also to be traced along the channel of the Forth.

The drainage system of the region throws considerable light upon its physical history and offers further evidence of the influence of the ice-sheet throughout the area. In several cases—*e.g.*, the Water of Leith and the Braid Burn—the present streams have reinstated themselves in their pre-glacial courses by cutting a channel down through the boulder clay, which filled them as a result of the passing of the ice-sheet. A remarkable series of dry valleys extends from near the valley of the North Esk at Rosslynlee through Carrington parish. The largest of these is about three miles in length, and runs parallel to the 600-foot

contour. With the exception of a small irrigation ditch and a tiny brook, which carries off the rain-wash from the slopes of the valley towards its eastern end, the valley is dry. The Dalhousie Burn cuts this valley at right-angles, but its course is unaffected by the dry channel. The floor of the valley consists of glacial deposits of sand and gravel, and all the evidence leads to the conclusion that, like the valleys at St. Helen's Church, Deuchrie Dod, and the Chesters Quarry ravine in East Lothian, these dry valleys were formed during the retreat of the ice-sheet from the region and before the natural drainage system was re-established. Towards the south-east corner of the region another well-developed dry valley has been produced by different causes—namely, through the action of the Gore Water in capturing the combined streams of North and South Middleton Burn, which formerly flowed into the Tyne, but which now empty their waters into the South Esk and have left their former channel, extending for almost a mile to the north-east of Borthwick as a dry valley. The influence of the ice-sheet is well marked in the Pentland passes, especially in the valley of Glencorse Burn, with its hanging valley at Loganlee and its well-developed corrie. The rivers of the region present many other interesting problems—*e.g.*, the direction followed by Bavelaw Burn. The remarkable bend in the course of Gogar Burn, which becomes a tributary of the Almond instead of following the more natural direction towards the Water of Leith, and the bend in the North Esk below Hawthornden.

The climate of the region bears a close relation to its topography. The prevalent west and south-west winds give rise to a mean annual rainfall of over fifty inches in the highest slopes of the Pentlands; the area over 1,000 feet has a rainfall of over forty inches; the isohyet of thirty inches roughly coincides with the 250-foot contour, and in the vicinity of Edinburgh we find one of the driest areas in the country. The city of Edinburgh has an annual range of 21° F., and throughout the greater part of the lowland area the July temperature is two degrees higher than the minimum of 56° required for the ripening of wheat and barley. In its yield per acre of these two cereals the region holds the premier place in the kingdom, but more remarkable is its superiority in the production of hay from clover and grasses under rotation.

The mineral resources of the region are as great as its fertility. Over 98 per cent. of the oil shale produced in the kingdom comes from Linlithgow and Midlothian, and sulphate of ammonia, paraffin wax and oil form an important part of the export trade of Leith and Grangemouth. The attempt being made to work a thin seam of shale on south-east side of Pentlands, if successful, will vitally affect a district at present devoid of population. The development of the Midlothian coalfield is proceeding, and this basin, along with those in Fife and Clackmannan, must become still more important as the western coalfields become exhausted. The region is rich in building stone. Moreover, the abundant supply of lime has favoured the building industry, besides meeting the demands of the farmer for a fertilising agent and of the ironfounder for a flux.

While the geographical advantages of the site favoured the rise and development of Edinburgh, other factors have also played an important part. The selection of Edinburgh as the seat of the law courts and of the university led to a demand for printing, and since 1507 printing has been one of the most important local industries. This gave rise to a demand for paper, and many mills are found along the banks of the Esk and the Water of Leith. The properties of the water drawn from the calciferous sandstone in Edinburgh and its neighbourhood have favoured the rise of the brewing industry. A large number of bleaching fields have been established on the banks of the Water of Leith.

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4. *The Underground Waters of the Castleton District of Derbyshire.* *By* HAROLD BRODRICK, *M.A.*

To the west of Castleton and 600 feet above it is a long valley, in the base of which runs one of the transverse Pennine faults. This fault brings down the carboniferous limestone, so that the streams to the north run over the Yoredale rocks to sink into the limestone. There are several streams, but only one ends in a cave of any size, the Giant's Hole. This has been explored for a distance

of 410 feet, where the water sinks in a deep pool. These waters run through an unknown course near which is Elden Hole, a vertical shaft 200 feet deep, with a further drop of about 50 feet below. This is now dry. The water is next met with at the upper end of the Speedwell Cave, where it wells up from a deep pool. The stream flows through the Speedwell Cave for 800 feet into the disused workings of the Speedwell Mine, being joined on its way by another passage 500 feet long, at the upper end of which is a fine chamber. The combined streams flow through the old workings for 1,000 feet, and finally fall into the so-called 'bottomless pit,' which is actually 90 feet deep, the bottom being filled with water 22 feet deep. The upper extension of the pit has not been explored within historic times, although the miners evidently climbed it. From the Bottomless Pit to the entrance of the Speedwell Mine there is a straight flooded working 750 yards long, through which visitors are taken in boats. The next point at which the stream is met with is at the upper end of the Peak Cave. It flows in here at two points, which passages are found to join at about 100 yards from the portion of the cave ordinarily visited. The total length of the Peak Cave ordinarily visited is 1,528 feet.

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5. *Further Exploration of the Mitchelstown Caves*, 1908–10. *By* Dr. Charles A. Hill, *M.A., M.B., D.Ph.*

An account of these two caves, as far as was then known, was read by the author at the Dublin Meeting, 1908. Since that date two visits have been paid to the spot, and an exhaustive exploration and survey of both caves completed. Some of these results have already been published in the 'Proceedings' of the Royal Irish Academy (1909). The present paper detailed the results of the latest exploration in March 1910, and was illustrated with numerous lantern slides of stalactite formations within the caves, together with maps and plans. The total length of the passages surveyed in the two caves measures about a mile and a half.

Section F.—ECONOMIC SCIENCE AND STATISTICS.

President of the Section.—Sir H. Llewellyn Smith, K.C.B., M.A., B.Sc., F.S.S.

THURSDAY, SEPTEMBER 1.

The President delivered the following Address :—

What should be the scope, form, and contents of a presidential address to the Economic Section of the British Association?

If we attempt to solve this question by the historical method we obtain indecisive results, for a hasty glance at the addresses of my predecessors in recent years shows a very wide range of variation, from the detailed examination of some particular point of economic theory or practice to a general survey of the past, present, or future of Economic Science, or a funeral oration over the grave of some obsolete school of thought. Nor does the comparative method—the examination of the prevalent customs in other sections of the British Association—give any clearer guidance.

If we fall back upon the *à priori* or deductive method it may not be difficult to construct some theoretical ideal of what a presidential address should be. Thus it might be suggested that the opening address should be to the general proceedings of the section what an overture is to an opera—introductory, suggestive, occasionally reminiscent of previous works of the series, touching skilfully on the principal 'motives' of current discussions without resting too long or too heavily on any. It should doubtless include a systematic and impartial review of the whole range of contemporary economic activity both on the scientific and on the practical sides, with just enough accompaniment of judicious applause or censure, encouragement or warning, to maintain the interest and to afford the necessary light and shade, while avoiding the dangers of polemical controversy which would provoke a desire for retort and refutation.

Unfortunately, *à priori* reasoning notoriously depends upon hypotheses, which rarely correspond accurately with realities, and which in the present case are veritable feet of clay. In particular our theory presupposes that the Council of the British Association have appointed a President who has the necessary leisure of mind to keep himself fully abreast of economic thought and research throughout the world, and who can devote to the pursuit of economic science that unremitting and undistracted attention which the economic man is popularly supposed to devote to the pursuit of wealth. Lastly, he is also assumed to be in a position of untrammelled freedom to tell anything he happens to know. Instead of this the Council have selected a hard-worked official with little leisure for the pursuit of any subject outside the range of his official duties, while as regards subjects within that range (including almost every branch of applied economics) the very nature of these duties imposes the most stringent reserves on his power of free discussion.

Nor does this disability arise from any formal rule or prohibition or considerations of official etiquette. It is the inevitable result of the working of natural laws which connect causes with their consequences direct and indirect, immediate and remote. Were I to-day to discourse to you freely and without reserve on questions of fiscal policy and commercial treaties, industrial combinations, railway

agreements, and shipping rings, patents and copyright, merchandise marks, labour organisation, bankruptcy legislation, and municipal trading, I think that I could probably afford you an hour's entertainment which might be both interesting and instructive, but I should look forward with some misgiving to the reactions of my indiscretions on the future working of the machine of which I am an attendant.

This, then, being the plight in which I find myself, my only course is to do the best I can under rather unpropitious conditions, to put before you without much order or system such thoughts and ideas as occur to me with regard to recent and present economic tendencies, and, if I must be indiscreet, to confine my indiscretions within reasonable limits.

But at the outset I must pause to say a word or two as to our losses during the past year. Death has been unusually busy of late in the ranks of economists, and hardly any important country has escaped its ravages. I can only mention a few of the more important losses.

To take our own country first, we are mourning the loss of the recognised doyen of economic statistics. Sir Robert Giffen was unequalled in his broad grasp, fine sense of proportion, and clear insight in handling masses of common statistics, and in extracting from them their real significance. But he was more than a statistician; his mind was extraordinarily fresh and original, and there were few subjects within the range of practical economics which he touched without illuminating. Of Sir Robert Giffen as an official I speak from personal knowledge, for he was my first chief in the Civil Service, and I shall always remember the ungrudging help and the generous support and appreciation which he bestowed on his staff and colleagues.

Looking across the sea we share the regrets of our American colleagues for the loss of Simon Newcomb, a great astronomer who had also made a name among economists for the freshness, vigour, and originality of his frequent incursions into the domain of our science; and also of Professor Sumner, of Yale, who stood very high indeed among economic teachers.

In Léon Walras, France has lost a distinguished economist whose most important work belongs to a past generation, but whose death severs one more of the few remaining links with the period of the first revolt against the doctrinaire successors of the classical economists. Walras was one of the early rebels, and he shares with Menger and Jevons the honour of being a pioneer of the application of mathematical methods to economic theory.

Another and yet more recent loss sustained by France has been the death of Emile Cheysson, distinguished both as administrator and statistician. His work was of particular importance in those fields of social enterprise in which the mathematical methods of the actuary are needed to place philanthropic effort on a sound basis, and he also devoted much personal energy to the promotion of schemes for social improvement.

The untimely and almost tragic death of Ernst von Halle occurred on June 29, 1909, and therefore falls just outside the period of the last twelve months. But I cannot pass over in silence the loss which Germany has sustained by the death of this brilliant young economist and public servant. Von Halle was probably best known in this country by his study of Trusts, published at a time when industrial combinations were only beginning to attract the attention which has since been so abundantly bestowed on them. But perhaps his most characteristic work was done in connection with the maritime development of Germany, and one of his latest economic writings was the essay which appeared in the 'Economic Journal' eighteen months before his death, in which he endeavoured to combat misapprehensions as to the historic basis, the objects, scope, and necessary limitations of a movement which is of such profound interest to the world at the present time.

One of the most notable losses of the year has been that of Nicholaas Gerard Pierson, the economist statesman of Holland, who was not only unquestionably the most distinguished of contemporary Dutch economists, but who for four years (1897-1901) occupied the post of Prime Minister of his country.

Austria mourns the loss, at the age of sixty-one, of Dr. Franz Ritter von Juraschek, head of the Austrian Central Statistical Commission, whose eminent

services to statistics were especially fruitful in the domain of international comparisons.

Two other veteran economists have passed away—namely, Dr. Julius Kautz, the Hungarian economist, at the age of eighty; and Professor Aschehoug, of Christiania, at the age of eighty-seven. Kautz is a link with the time of Roscher and the early German historical school. Aschehoug had occupied a professorial position in the university for fifty-six years.

Turning from the review of our losses to the progress of economic science and statistics during the past year we find perhaps little that is sensational to record, but much evidence of quiet, steady, and solid progress along various lines of research. I am now, of course, speaking of the output of new and original economic work, not of the popular discussion of practical economic problems, which has been perhaps more active and persistent, not to say blatant, during the last twelve months than in any corresponding period of recent times. For reasons which I shall indicate presently, I am by no means inclined to take a purely cynical view of the value of these popular discussions even when carried on amid the heat of party politics. Good as well as evil, and often in greater measure than evil, may, and I am convinced does, result in the long run to economic science from popular discussions of economic questions, however superficial they may be, and however distorted by bias and passion. But it is not of this sort of thing that I am now speaking, but of modern economic work and thought properly so-called.

Among the most welcome tendencies of recent economic thought and writing has, I think, been a marked falling-off in the sterile and strident controversy that has so long been carried on between the advocates of different methods of research. We might, I think, be justified in saying that a truce, if not a permanent peace, has been declared between the champions of the so-called historical and abstract or analytic methods, based on the mutual recognition that both methods are indispensable, and are, when rightly used, complementary rather than antagonistic. The metaphor of the two feet which are necessary for walking (or at least for any advance which is other than a series of spasmodic hops) seems to have brought comfort to some who, a short time ago, were at death-grips. This happy cessation of a controversy which, though once big with great issues, has of late years been little but a barren academic wrangle, is pure gain to economic progress; for it may be taken as a general rule that long-continued and acrimonious controversies about scientific method are a sure sign of a low level of scientific achievement. When men of science and action have important work on hand they have no time or use for elaborate polemics and recriminations as to the proper tools and apparatus to employ. Not, of course, that the problems of method are ever unimportant, but in times of real active advance they occupy a secondary place and are naturally and almost unconsciously solved in relation to each positive economic question as it arises. It is only at times of low positive activity that the question of method assumes an independent position as the dominating problem of the day.

If we were to apply both the historical and analytic methods in combination to the elucidation of the controversy between them which is now dying down, it would, I think, appear that the supposed opposition between the two schools of method, so far from being fundamental, arose largely from circumstances which were local and temporary, that the antagonism was for a time both necessary and fruitful, but that it has long ceased to have either of these characters, and has been a real obstruction to advance. No doubt the pursuit of the two branches of research will remain to a large extent distinct and in separate hands, owing to the natural division of labour according to personal tastes and aptitudes; but the historian and the theorist will each in future be clearly conscious that the work he is doing is only partial and one-sided, and cannot be made complete without the assistance of the other. And both will, I hope, be conscious to an increasing extent of their common dependence on a third line of research, at present only in its infancy—namely, the quantitative investigation of economic phenomena mainly through the scientific study of statistics. I do not know whether statistical investigation has been conceived as forming one or more toes of both or either (and, if so, which) of the two now famous feet on

which political economy is said to rest, but it certainly seems to be an indispensable adjunct to both. At a very early stage of abstract analysis it is usually necessary to give due proportion and precision to our ideas by clothing the dry bones with the flesh of concrete facts, and across the flow of economic phenomena which history investigates we need to take frequent sections and soundings if we desire to measure effects as well as to trace causes. I have some doubt if the economic animal is a biped after all. I do not want to make him a centipede, but I think that at least three feet must be postulated—abstract analysis, historical (including comparative) investigation, and concrete statistical measurement.

The reconciliation of the historical and analytic schools of research does not diminish, perhaps it increases, the necessity for perpetual vigilance on the part of investigators of both types against their peculiar besetting sins. The historical inquirer, full of his doctrine of relativity, must beware of supposing that he justifies an institution when he unfolds its origin and shows how it grew naturally out of the conditions and circumstances of its day, or that he conclusively condemns its continuance when he shows that the conditions and circumstances of its origin have passed away. On the other hand, the analytical reasoner needs to be continually on the watch to detect in his assumptions which appear universally valid the elements which in reality are true only for particular times and places.

The next tendency which I notice in recent economic literature is one which can only be welcomed with some qualifications. I refer to the increasingly technical character of the phraseology and methods employed. Economic and statistical science is in the course of elaborating a highly specialised technical terminology of its own, so that no careless reader may be misled by an ambiguous word or phrase. Since the fundamental terms of economic science are words in common use, such as wealth, capital, wages, rent, prices, and the like, each of which is used in everyday conversation in half a dozen different senses, and none of which have any claim to scientific precision, it can be readily understood that the greatest of the classical economists was not always proof against the danger of using his terms in different senses in different portions of his argument, while the pamphleteer successors of the early economists scarcely made a serious attempt to use terms in a consistent way throughout.

Hence the great convenience for the purpose of analytical reasoning of having a purely scientific terminology, free from ambiguity and incapable of being confused with the popular words used in the market-place.

And yet while welcoming the movement which has given us such terms as 'flow,' 'national dividend,' 'consumers' surplus,' 'quasi-rent,' and the like, I venture to sound a mild note of warning. All these special terms and the technical reasonings into which they enter should be restricted so far as possible to purely scientific publications, and even in these their meanings should be carefully explained and not assumed. I do not say this wholly or mainly in the interests of the popular reader, but quite as much, and perhaps more, in the interests of science. Political economy cannot from its nature ever be in the position, say, of mathematical physics, which, though necessarily a closed book by reason of its abstruseness to the vast majority of intelligent persons, nevertheless commands their complete confidence. No one is afraid to trust himself on a bridge because he cannot follow the reasonings which have made the engineers confident in its stability. He accepts the results though he cannot follow the process. But I do not think that the ordinary man will readily take up this attitude towards a science like economics dealing with matters of everyday life which he deems himself fully competent to understand and discuss. If then the language of economic science is to him an unknown language, he is likely to pass it by as an affair of a clique having no relation to practical life. This might not perhaps matter much if we could get along without the practical man, but we cannot, because we need his criticism at every point. A vast amount of rubbish is, of course, said and written annually on economic matters by persons who are imperfectly equipped for the task either of discovery, exposition, or criticism; but this should not blind us to the fact that a great deal of very valuable economic criticism comes, and still more ought to come, from men who are not professional

economists, and who have no leisure to keep themselves abreast of the newest modes of professorial expression. Now it is of the highest importance that we should do everything to encourage and nothing to deprive ourselves of this criticism, which is essential in order to keep economic thought sane and sound and in touch with realities. On all grounds it would be deplorable if through the obscurity of its language economic science should relapse into the position of an esoteric doctrine confined to a small circle of initiates, only the bare results of which are capable of dogmatic statement to the outside world. Not only is the doctrine unlikely to be accepted on these terms, but, being *ex hypothesi* a doctrine elaborated in the closet by experts without contact with the fresh breezes of everyday business experience, it is quite certain to suffer in balance and proportion and reality, and in all that gives it value to the world.

Of course the vast bulk of public criticisms and suggestions on technical projects or scientific theories are shallow, irrelevant, and futile. But even though there be 99 per cent. of chaff, the odd 1 per cent. of grain may well be priceless. Now I would say very seriously that it is of the highest importance to our science not to be cut off by any barrier of unintelligible phraseology from the advantage of the co-operation, whether by criticism or suggestion, of that great body of persons who, while not professional economists, are practical experts in one or other of the branches of economic knowledge.

What I have said with regard to the use of special technical phraseology in economic reasonings intended for the eye of the general reader applies of course with special force to the use of mathematical symbols and modes of expression. I do not think that either by taste or training I am likely to underrate the value of mathematical methods in elucidating economic problems. The essentially mathematical conception of functions and mutually dependent variables offers incomparably the most powerful and appropriate method of expressing the interrelations among such economic phenomena as rent, interest, price, wages, product, and capital. Moreover, the apparatus of the infinitesimal calculus affords the only satisfactory mode of representing and analysing continuous economic changes. Ordinary verbal argument on complicated questions (say) of international values or of the ultimate incidence of taxation, can hardly go beyond the analysis of certain particular cases of discontinuous changes selected for purposes of illustration.

Nevertheless, I trust that those who recognise with me the value of mathematical modes of expression will be extremely careful to restrict mathematical language to the pages of technical economic journals or the footnotes and appendices of more popular treatises, and to re-state all the conclusions arrived at by this means, with at least an outline of the arguments which lead to them, in ordinary language free from technical symbols.

The last-mentioned condition is, I think, important, not merely for the reasons which I have already given, but for another which applies peculiarly to mathematical arguments. Before starting our mathematical analysis we are bound, of course, to define very precisely the meaning of the quantities which the symbols express, and this in itself is very salutary, for it compels us to recognise frankly the hypotheses on which our argument will depend. But when the mathematical process has once begun we very quickly lose sight of the economic contents of the symbols. As the school-girl in the examination said: 'Algebraical symbols are what you use when you don't know what you are talking about.' Now from the point when we lose sight of the economic significance of our symbols we lose the means of applying the check of common-sense to the intermediate stages of our analysis, and we do not recover this power of criticism until the final results emerge and are interpreted in ordinary language. Between the points at which our economic assumptions are translated into mathematical formulæ and our ultimate results are re-translated into ordinary language, there is nothing to enable us to take stock of the position and to warn us of the direction in which we may be drifting.

Another tendency which I see in economic research is to attach increasing importance to quantitative measurement with the aid of the separate though auxiliary science of statistics.

This is a tendency which is wholly welcome and which is likely to become of increasing importance in the immediate future. Like all salutary movements it

is, of course, not free from incidental dangers. It is clearly possible to lean on the third foot of our tripod more heavily than it will bear, and it is not only possible but probable that the public demand for quantitative information will for some time outrun the available means of supply. Certainly the pressure for more and better statistics is increasing very rapidly at the present time, and not always with due regard to the limitations of what is practicable. In order to form a sound and sober judgment of the true possibilities of advance along this line it is necessary to recognise frankly the chasm which separates the crude and primitive means of measurement, or rather of quantitative estimate, which alone are open to the economist, from the relatively perfect apparatus and methods which are available to the physicist.

But the more imperfect our data and the more primitive our means of enumeration and measurement, the more perfect and complex needs to be our scientific apparatus for criticising the results and enabling positive inferences to be drawn therefrom. In other words our dependence on statistical science is proportionate to the defects of our means of direct and accurate measurement.

Statistics is often classed with economic science (and, indeed, the two names are linked in the title of our Section) as though there were some essential connection between the two. But this, of course, is not the case, statistical methods being used to a greater or less extent in all the branches of science which occupy the other Sections of the British Association. In fact, it is probably in connection with biology rather than economics that the most important original research by statistical methods has been recently carried out.

Quantitative measurement is the backbone of science, and whenever the quantities handled are in any way indeterminate or inexact, either in regard to their definition or enumeration, we need the assistance of scientific rules and criteria to enable us to correct, or neglect, or at least to limit the error introduced into our results by the faulty nature of the data. The mere direct measurement, counting, or weighing of quantities is scarcely worthy of being called a statistical operation: statistical science properly so-called is mainly concerned with establishing the conditions under which approximately true inferences may be drawn from imperfect data. On this problem the modern statistician brings to bear the powerful engine of the mathematical theory of probability.

It is no part of my intention to attempt to discuss the methods of modern statistical science: I only wish to emphasise the close connection between the elaboration of these methods and the imperfection of the data to which they are applied.

Now the data of economic statistics are almost all liable to error either through defects of definition or extension. Either the only data available are not precisely of the nature required for the purpose of the particular investigation, so that we have to do the best we can with second or third best materials, or the data obtainable only cover a comparatively small portion of the total field, and there may be formidable questions as to how far the results based on such limited data are really representative. Sometimes we suffer from both these difficulties, and statistical inquiries oscillate habitually between the two dangers as between Scylla and Charybdis—the danger on the one hand that over-insistence on elaborate precision of data may so narrow the field that the results obtained from the sample may be unrepresentative of the whole, and the danger on the other hand that the 'common statistics' which alone cover the whole field are necessarily obtained not only for one but for many diverse purposes, and are therefore unlikely to be entirely appropriate to any particular inquiry. Between these characteristic dangers of the intensive and extensive methods respectively we have to steer our difficult course as best we may.

The peculiar dangers of the intensive method are so obvious as not to need special emphasis. Everyone is aware that better results are obtained from a wide than from a narrow range of observations, and indeed I think that the besetting error of the public is to attach too much rather than too little importance to this defect. It requires a trained observer to understand how few samples if honestly chosen at random suffice to give a good approximation to the truth.

But one special difficulty which attends the extensive method often receives, I think, less attention than is its due.

Statistical investigations which cover very large masses of returns and are

repeated periodically so as to admit of historical comparisons must from the nature of the case be based on what Sir Robert Giffen used to call 'common statistics.' The term 'common' is not used in any derogatory sense, but in its strict meaning, viz., statistics not designed or compiled specially for one particular purpose, but destined to serve several purposes in common. The obvious reason for this is that human beings are not willing to spend their lives in filling up forms of inquiry to suit the needs of every statistical investigator. There being, therefore, limits to the amount of statistical data which can be extracted from the public, it follows that returns filled up primarily for one purpose have to serve several other purposes as well.

A single example of the multiple use of common statistics will suffice, viz., the statistics of foreign trade.

Primarily the classification of the foreign trade statistics of every country is based on the subdivisions of its Customs tariff, the object being to enable the operation of the tariff to be watched. Of course, in the case of the United Kingdom, where Customs duties are now confined to a small number of articles, the existing tariff classification has but a minor effect on the classification of the trade accounts, though even our trade accounts show abundant traces of the influence of the tariff subdivisions of bygone days. But in protectionist countries the statistics of foreign trade are practically governed by tariff considerations, and international statisticians are fully aware of the difficulty which tariff variations place in the way of the attainment of statistical uniformity among the different commercial countries of the world.

The second purpose the trade accounts have to serve is that of the practical trader, who is concerned not at all with the attainment of statistical uniformity, but very much with the safeguarding of his own particular trade interests, and who therefore wishes for a classification which will furnish him with all the data needed for his business, while suppressing all details that will serve the purpose of his trade rivals and foreign competitors.

When we have reconciled the claims of the Customs authorities and the practical trader we have to meet the insistent demands and criticisms of persons interested in public affairs who wish to learn from the trade accounts what is the true economic state of the nation, in comparison either with its foreign rivals or with some previous period of its own history. But it is very soon discovered that the requirements of these critics, while not always compatible with those of the practical trader or the financial authorities, are not consistent among themselves. So far as they wish to make international comparisons they recommend modifications which would assimilate our classification to that of foreign countries, but so far as they wish to make historical comparisons they deprecate any changes of classification that will impair continuity.

It is not necessary to labour the point further, though illustrations perhaps even of a more striking kind might be afforded by the multiple uses to which the results of the general census are put.

Thus those who collect and compile common statistics have to serve many masters—sometimes with the usual result. If every statistical enthusiast had his way and the declarations required from traders and citizens were adapted to meet the precise requirements of each investigator in turn, the schedule to be filled up would be something from which the practical business man would recoil in horror. Hence, in practice, we are driven to a rough compromise between divergent and conflicting aims, relying on the resources of statistical science to enable us to apply the needful qualifications to the necessarily imperfect results.

So far we have only been dealing with the apparatus and methods of research and exposition, and not at all with the objects to which such research should be applied, still less with the ultimate ends of economic study and conduct.

The next tendency we have to note belongs to quite another region of ideas. This is the growing emphasis laid on ends as distinguished from means as the subject of economic study.

There used to be some disposition to question whether the economist was at all concerned with ends, whether he had not fully discharged his duty in making a correct analysis of the structure of existing economic society and of the forces acting upon it; and it was rather the fashion to suggest that when this analysis

was completed the economist should depart, and leave the practical statesman to collate his report with those of the moralist and the politician, and to draw the necessary inferences as to practical policy from their combined study.

Such a limitation as this would have been quite foreign to the ideas of the early makers of political economy. The mediæval thinkers were frankly concerned with economic conduct and morals; the mercantilists with the very practical question of adapting economic policy to the race for national power; the physiocrats with the freeing of pre-revolution France from the network of vexatious and oppressive State restrictions on industry with a view to giving free play to the natural expansion of manufacture and commerce. Malthus was engaged in combating social utopias, while Adam Smith was concerned, as we have been recently reminded in Professor Nicholson's striking book, with every field of political and moral activity, as well as with that region within which economic science is usually supposed to be confined. The author of the 'Wealth of Nations' would certainly have been astonished at the suggestion that political economy is not concerned with ends. Yet the first step towards at least a temporary divorce between the study of economic ends and means was taken when Adam Smith enunciated his famous conclusion that 'all systems, either of preference or of restraint . . . being . . . completely taken away, the obvious and simple system of natural liberty establishes itself of its own accord.'

I am not concerned to discuss whether this conclusion was an induction from experience or a deduction from moral or theological presuppositions, or how far it is to be qualified by many other passages in the same great work. But in any case the proposition that the natural forces of human desires and aversions, and their mutual reactions, will naturally and without conscious intention on the part of the individual lead to the greatest advantage of society, became the starting-point of a school of propagandists of economic truth who too often identified the indicative with the imperative mood, and blurred the distinction between scientific generalisations and moral precepts of conduct.

To those who adopted this view of the Economic Harmonies in its extreme form the question whether political economy is concerned with ends as distinct from means became a relatively unimportant question, and fell naturally into the background.

The maximising of production (or, as we should now say, of the national dividend) is the only end that these economists could be said to propound, the distribution of the resultant wealth being automatically determined by the beneficent action of the 'system of natural liberty.' Sooner or later the current utilitarian philosophy, with its principle of 'greatest happiness,' was bound to come into conflict with this ideal, for the policy of maximising satisfaction is clearly not identical with that of maximising production. The enunciation of 'maximum satisfaction' as an end necessarily raised—though it could not solve—the question of distribution of wealth among different social classes. In regard to this matter it shook confidence in the shallow dogmatism of the propagandist economists, but it substituted no definite alternative commanding general assent, and accordingly the immediate practical result on economic thought was not to inspire it with a new creed, but to deprive it of all creed, and to replace the art of political economy by the conception of an economic science concerned solely with the ascertainment of the results which flow from certain hypothetical assumptions, and not at all with guiding mankind towards a desirable goal.

Such a view could hardly hold permanent sway, though it was a great advance on the dogmatic and insolent optimism which it displaced, and nominally at least it dominated English economic thought from the middle of the nineteenth century almost to the present day. This domination has, however, been more nominal than real. The limitation was from the first subjected to vigorous criticism, and at bottom the critics were right, for however carefully we may expel the idea of ends from our reasoning, current ideals and even prejudices are certain to affect our choice of hypotheses. As a fact, all the latter-day economists have by one expedient or another escaped from their own theoretic limitation. To take a single example, it has become a recognised axiom of economic reasoning that the diminution of poverty is a proper object of economic effort. Of course, the pure utilitarian would have nothing to do with distinctions of quality in happiness—distinctions which are fatal to the simplicity of

his magic formula—and the utilitarian school of economists attempted no direct discrimination in their measurements of utility and value between the qualities which render an article an object of desire. The fact that a thing is desired proved its right to be called 'useful' within the meaning of their theory, and it must be admitted that no coherent objective theory of value could be built up on any other basis. Nevertheless, it is no new discovery that things of equal value to the individuals who possess them at a given moment may conduce in very different degrees to the ultimate national advantage. The old distinction between productive and unproductive expenditure, and Adam Smith's difficult argument as to the relative advantages of near and distant trade, are examples of distinctions of this kind which were present to the minds even of the economists who were most dominated by the theory of natural liberty.

The great and growing importance attached by the best modern economists to the element of time, and the consequential recognition of the importance of ultimate as distinct from immediate effects, tend *pro tanto* to discriminate between different qualities of satisfaction, and to give increased weight to those kinds which tend to the building up and husbanding of the permanent economic interests of the Commonwealth, as compared with the transitory satisfactions which perish in their own gratification—in short, between the nobler and ignobler forms of utility.

I think it is a matter which needs the careful consideration of economists at the present day, whether the time has not come when they should accept fully and frankly the task, from which in any case they cannot entirely escape, of distinguishing between noble and ignoble ends of economic conduct, and should regard all their methods of research—historical, analytical, comparative, and statistical—as only means to this end.

On the present occasion I cannot do more than illustrate my meaning by a single important example.

The recognition that the purposes and modes of consumption of commodities have to be taken into account, as well as the mere amount of the satisfaction yielded by them to their consumers, brings with it the necessity for recognising the distribution of income in respect of time, no less than in respect of class, as an essential factor in the national well-being.

Thus, for example, a regular income of 2*l*. a week may have a very different economic significance from an income amounting in the aggregate to 104*l*. in the year, but receivable in irregular and unequal instalments. Still more widely does it differ economically from the chance of a variable income averaging 104*l*. one year with another.

Now one of the most significant and important economic tendencies of the present day is the growing recognition of the importance of security and regularity in all operations of industry and commerce. It is, of course, a trite commonplace that the foundation of commerce is security—that safety of person and property and security for the performance of legal obligations are essential conditions of all industrial and commercial development. But it is not of these elementary guarantees that I am speaking, but of the tendency which I see to attach ever greater importance to the certainty and regularity of sequence as distinguished from the mere aggregate volume of business transactions. This tendency is reflected in the enormous development of the method of insurance as a protection against risk.

Nor is this development confined to business transactions properly so-called. A number of the risks and contingencies of human life which cause irregularity and uncertainty in working-class incomes have been brought within the sphere of insurance, whether by voluntary institutions, or, as in Germany, by a State system of organisation. And the question of the perfection and further development of the methods of social insurance is absorbing a large amount of the best thought of the day.

All this points to the growing importance attached by social observers to stability and regularity, and the grounds for this attitude are sufficiently obvious, whether we look at the matter from the point of view of the economy of the workman's household, or of the deteriorating effects of irregular habits on physique and character. It may perhaps be suggested that the growing social concern for

the maintenance of stability is the counterpart of the growing conviction that with the world-wide development of industry the causes of fluctuations and irregularity are becoming continually more incalculable and their effects more unavoidable by unaided individual effort.

Is this tendency to exalt security as an end a healthy tendency, or ought it to fill us with apprehension?

The ideal of security may not at first sight seem a very heroic aim to put before a country whose economic traditions form a veritable romance of adventure full of the joy of risks encountered and dangers overcome. Some may think with misgiving that the conscious pursuit of a policy of safety implies that we have passed the stage of economic youth and expansion and are entering on the dusk of old age. They may feel as when at Rome we contemplate Aurelian's great wall which for centuries withstood the inroads of barbarians, but the building of which none the less marked the definite close of the period of the fearless and aggressive supremacy of Rome. Are the nations of Europe being invited to enter with the old gods into the fortress of Valhalla, there to await in well-planned security but in growing gloom their inevitable decline? The question is cogent and searching, and modern nations must find the true answer at their peril, for if the two ideals of free adventure and economic security admit of no reconciliation, then the fate of our civilisation is only a matter of time.

But fortunately it is not necessary to admit the essential opposition of these two ideals rightly conceived. For as it seems to me there is a noble as well as an ignoble ideal of adventure, and, corresponding thereto, there is a noble as well as an ignoble ideal of security, and the great problem that lies before us in the future is to distinguish rightly between them and to direct our national policy accordingly.

The first step towards making this distinction is to recognise that ignoble as well as noble results are produced by exposure to risks. If fearless resolution and foresight in encountering and combating danger and risk produced the race of Elizabethan mariners and explorers, and to-day gives us a Shackleton or a Sven Hedin, we know also the craven and panic-stricken population which lives on the slopes of a volcano, exposed every day to incalculable risks against which no precautions can avail.

It is, I think, a definite induction from history and observation that when risk falls outside certain limits as regards magnitude and calculability, when in short it becomes what I may call a gambler's risk, exposure thereto not only ceases to act as a bracing tonic, but produces evil effects of a very serious kind.

It is to the general interest, and it tends to the building up and strengthening of the national character, that everyone should have as strong a motive as possible to guard against risks which can be avoided by reasonable precautions on the part of the individual, and it is also to the general interest that within certain limits the individual should have sufficient resisting power and reserve strength to encounter without the support of his fellows the ordinary minor ups and downs of life which it is not within his power to avoid. What these limits are cannot be laid down dogmatically: they vary widely from nation to nation, from class to class, and from age to age. Vicissitudes which mean famine to the savage pass quite unnoticed in advanced industrial communities, and classes who are accustomed to yearly salaries are unconcerned with fluctuations which bring privation to the weekly wage earner. But within any given nation and class the limits probably change but slowly, and though different schools of social observers will certainly fix the limits at somewhat different points, and there is no doubt a neutral zone within which the relative public advantages and disadvantages of exposure to risk are fairly equally balanced, or at least may be open to legitimate debate, I am disposed to think that the majority of fair-minded men would not differ very widely in the principles governing the demarcation between the spheres of individual and of social protection against economic risk. To take, for example, the risks of unemployment, I think most people would agree that the personal risk of losing employment through bad work, irregular attendance, or drunken habits is one which it is absolutely necessary in the public interest to leave attached in all its force to the individual workman. For the community to guarantee employment to all irrespective of personal effort or efficiency would necessarily impair the national character and lower the national standard. This is, therefore, a risk

the direct incidence of which must be borne by the individual, the action of the community being confined to such indirect measures as may strengthen the power of the individual to meet the risk, as, for example, by technical and general training.

On the other hand, I think that most people would agree that in a country like the United Kingdom at the present time, the incalculable risk of a prolonged depression of trade, due perhaps to some financial catastrophe thousands of miles away, is one the exposure to which of the individual workman does little but harm. Such a risk is too much beyond his powers of foresight, and also too great in magnitude in proportion to his reasonable opportunities of making provision, to exercise any appreciable effect in stimulating self-help, while the liability to see all his savings swept away in a few weeks by cyclical fluctuations in employment which he can do nothing to avoid is a demoralising risk acting on his character precisely like the liability to earthquake or other cataclysm, and discouraging to a marked extent the accumulation of savings and the development and maintenance of habits of providence.

Between these two extremes, the risk due to personal inefficiency and that resulting from a world-wide depression of trade, lie intermediate classes of risks about which there might be more difference of opinion, and the incidence of which probably acts on national character in very different ways in countries at different stages of development.

I propose presently to examine more closely some of these classes of risks. At the moment, however, I am only concerned to illustrate my general proposition that neither free adventure nor economic security suffices singly as an ideal of economic conduct without careful discrimination, and that the criterion for such discrimination is the effect of exposure to each class of risk in building up or degrading the national character.

In suggesting that the attention of economists is being directed and will continue to be directed in an increasing degree to the ends of economic conduct as distinct from a mere analysis and description of existing conditions, I have taken a single example, the pursuit of economic security as an objective, and have drawn a vital distinction between the classes of economic risks exposure to which tends to the building up or to the degradation of the national character. And as regards these risks I have taken a single illustration, that of unemployment, partly because the evils resulting therefrom have been very much in our thoughts during the last few years, partly because their analysis affords good illustrations of almost every class of economic risk.

I might go on to take other examples, but I think that it may perhaps serve a more useful purpose if during the time that remains to me I follow up in further detail the particular illustration which I have chosen, and inquire specifically how far the risks of unemployment are risks which it is expedient in the public interest that each individual should be left to meet unaided, or how far they are from the social point of view 'insurable risks' which can properly be met by combined action.

We shall find that the reply to the proposition is by no means a simple one, that it will differ to a large extent for different trades, and that probably it will also differ widely for different countries.

At the outset it is to be noted that I use the term 'insurable risk' for the purpose of this inquiry in a much narrower sense than that which it bears in the ordinary language of the insurance world. Broadly speaking, if the term be used in its widest sense there are no risks that are not insurable except those which are the result of the direct wilful act of the insured person. Thus you can insure against fire but not arson, against death but not suicide. And even with regard to acts which are voluntary the modern tendency is to take a very broad view, and to narrow the classes of cases excluded. Thus most life assurance companies will pay on death, even if due to suicide, provided that the policy was taken out sufficiently long before the death to make it fairly certain that suicide was not in contemplation at the time.

As I am now using the term 'insurable,' however, I mean not merely a risk in respect of which you could get some company or underwriter to quote you a premium, but a risk for which some sort of social insurance is a practicable and

appropriate remedy—bearing in mind the critical distinction already drawn between different classes of risks.

Moreover, by 'insurable risk' I do not mean a risk which can be fully covered by insurance, but one the consequences of which may be mitigated by a payment which nevertheless falls far short of complete indemnity. It hardly needs demonstration that full indemnity against the risks of unemployment could not be offered without disastrous results, inasmuch as a large section of persons regard idleness as in itself more attractive than work. The universal practice of organisations, voluntary or public, which insure against sickness, accident, or unemployment, is to make the benefit payable much less than the full rate of wages, and in all that follows this condition is assumed.

For the purpose of the present inquiry the causes of unemployment group themselves naturally under three heads—periodic fluctuations, local and industrial displacements, and personal causes.

Of these I have already touched on the first group in discussing cyclical and seasonal fluctuations of employment. Seasonal changes are, of course, the direct result of cosmical causes, and whether or not cyclical fluctuations are ultimately psychological or (as Jevons thought) cosmical phenomena, there can be no doubt that for our present purpose we may regard them as ultimate facts beyond the control of the individual. These two elements in unemployment are pre-*eminently insurable elements*, since, being due to recurrent oscillations and not to progressive changes, they can only be met by some method, either individual or collective, of spreading the earnings of good periods over good and bad alike, and not by any remedy which aims at altering the permanent relation between the demand for labour and the supply. Moreover, of the two alternative methods, collective insurance is more appropriate for the purpose than individual providence, because while the oscillations are fairly well defined, their intensity and (in the case of cyclical fluctuations) their wave length are affected by many uncertain elements, climatic, financial, industrial, and political, which are incapable of exact prediction, and (what is even more important) the personal incidence of the unemployment due to the oscillations is uncertain.

The next group of causes includes changes in industrial processes or methods or in the local distribution of industries, or in the character of industrial demand. How far are these classes of risks properly insurable?

As regards local distribution, the answer mainly depends on the scope of the insurance scheme. No purely local fund can, of course, compensate a workman for the shifting of his industry to other districts, without incurring ruinous expense besides impairing the mobility of labour. If, however, the insurance scheme be national in scope and be worked in conjunction with systematic machinery for notifying to the workman the existence of vacancies in other districts, the risk of unemployment due to local displacement is clearly an 'insurable' risk. As no national scheme could embrace a wider area than the United Kingdom, the above argument does not apply with its full force to the risk of displacement of industry by foreign competition, and this case needs separate treatment. It is undoubtedly a risk beyond the individual's control, and it has, therefore, one of the essential marks of an insurable risk; and if the scheme embrace a large group of trades of sufficient variety to insure each other against the risk of some particular branch being attacked by foreign competition, there is no reason why this class of risk should throw an excessive burden on a national fund. The only question to be considered is, therefore, whether the insurance of British workmen in an industry liable to be transferred by competition to a foreign country will operate prejudicially by checking industrial mobility, there being obviously not the same opportunity for the workman to follow the work as in the case of local redistribution of industry within the limits of the insuring country.

In this respect the case we are now considering is on all fours with that of a trade decaying through a permanent change of industrial demand, or an alteration of industrial processes. If there is appreciable mobility of labour between the decaying trade and other healthy branches embraced within the scope of the insurance scheme, and if its magnitude is small as compared with the total area of industry covered by the scheme, then the risk is fairly insurable. If, however, these conditions are not fulfilled, the case of the permanently decaying trade may

present a real though by no means insuperable difficulty which will have to be carefully borne in mind by those responsible for devising and working any unemployment insurance scheme.

The conclusion seems to be that the extent to which the risk of unemployment due to industrial and local displacement is properly insurable depends partly on a wise choice being made of the group of trades and of the geographical area to be embraced by the scheme, partly on the judicious limitation of the benefits payable thereunder. Our analysis points to the necessity of a large area, both geographical and industrial, and further suggests that the groups of trades included should be such as are unlikely as a whole to undergo wholesale and rapid displacement, and within which any decay to be apprehended is likely to be only local and partial and not on a scale too great to be compensated by the expansion of other branches of trade within the insured group.

There remain the risks due to personal causes. Of these we have already ruled out the risks due to the wilful act of the workman, and to these we must now add the personal risk attributable to exceptional deficiencies, physical, mental, or moral. These are not properly trade risks, the burden of which ought to fall in a special degree on those following a particular industry, and if they were allowed to do so they would ruin any scheme of insurance based on the trade group. There is still, however, one important class of personal risk to which all are liable, and which is in the main beyond the control of the individual, viz., the increasing liability to unemployment due to advancing years. I do not intend to trench on the important but quite separate problems of national provision for old age and invalidity as such. I am solely referring to the ascertained statistical fact that the chance of unemployment is a function of age, and that beyond a certain age the risk is materially increased. For example, among a body of nearly eight thousand engineers whose industrial records were analysed for the purpose, I found that whereas the average number of working days lost in the year by the whole body was fifteen, that for members below the age of forty-five was less than twelve, while for members between the ages of forty-five and fifty-five it was twenty, and for members between fifty-five and sixty-five, thirty-three. (Above sixty-five the figures are affected by superannuation.) The question we have to ask is, how far this class of risk is insurable?

The answer depends again on the scope of the scheme. A voluntary scheme which workmen are free to join and leave at their pleasure cannot deal satisfactorily with a risk of this kind, especially as no scheme of graduating contributions according to age is likely to be administratively feasible. Trade-unions which give unemployment benefit are in an exceptional position, because they exist primarily for trade protection purposes, and hence have a hold on their members which no voluntary insurance scheme pure and simple could possess. Generally speaking, personal unemployment due to advancing years is insurable, and only insurable, under a scheme which applies compulsorily throughout the whole period of the workman's industrial life.

It results from our analysis that some of the risks of unemployment are properly insurable and others are not, and the next step is to ascertain broadly the relative importance of the insurable and non-insurable elements. Now an examination of the available statistics indicates clearly that at all events as regards certain large groups of trades in which unemployment is acute—namely, the building, engineering, and shipbuilding trades—the insurable element in the risk of unemployment predominates largely over the non-insurable element.

The method of statistical proof of this proposition may be indicated as follows:—

1. The percentage of unemployment in these trades—taking an average of good and bad years together—has not varied very widely during the period of fifty years during which the statistics have been collected (the average for the first decade of the period was 5·6; for the second, 4·5; for the third, 6·8; for the fourth, 5·2; and for the fifth, 7·2. The average for the whole period was 5·9). As the period of oscillation is not exactly ten years, part even of the differences shown above is accounted for by the presence of an excessive proportion of good or bad years in particular decades. Thus we may fairly say that the element of unemployment due to progressive expansion or contraction of the demand for labour has been relatively small.

2. The percentage of unemployment found during the seven best years of the cycles has averaged 2·4, and only in two out of these seven years has it diverged by more than unity from this average.

3. The variation between the worst and the best years of the various cycles has averaged 8·5 per cent.—*i.e.*, more than three times the average percentage of unemployment in good years.

Now, broadly speaking, if we neglect any progressive changes in the total demand for labour, which are evidently slight as compared with the intensity of the periodic fluctuations in that demand, we may say that the percentage who are unemployed in years of good employment gives a maximum limit which the voluntary or non-insurable risk cannot exceed, since it also includes a number of minor accidental risks which are properly insurable—*e.g.*, the risk of unemployment through a fire or other accidental stoppage of work, or through defects in the local distribution of work and labour. Moreover, through the method of averaging employment over the year, and risk of seasonal want of employment is included, and this is mainly an insurable risk.

We may further regard the difference between unemployment in a good and bad year as giving a minimum measure of the insurable element in unemployment, since this difference is wholly the result of changes in the demand for labour, and is independent alike of the choice of the individual and of the gradual progressive changes, if any, that affect the total field of employment. Hence, as this difference is much greater than the minimum percentage in a good year, we may regard our proposition as being proved.

But at this point it is necessary to forestall and reply to an objection that will certainly be taken to the proposition just laid down. It will be pointed out that the experience of all relief works and of all schemes for the relief of distress due to unemployment establishes clearly that the great majority of the unemployed, or at least those who seek relief from distress, are very markedly inferior both as regards their industrial capacity and their physical and moral qualifications to the average employed workmen in the same trades. It is possible in a large number—probably in the majority—of these cases to trace clearly the operation of the personal defects which have contributed to unemployment—bad time-keeping, drink, slovenly work, and so forth—and those who are most familiar with the personal side of the problem are, I think, likely to put the personal or non-insurable element in the risk of unemployment very much higher than I have done in relation to the involuntary insurable element.

But in this criticism there is, I think, confusion of thought. Of course, if fifty men out of every thousand are out of work, those fifty individuals are likely to be less eligible than any other fifty taken at random. We might, if so disposed, construct a geometrical curve like those used in expounding the doctrines of utility and rent, in which the number of workmen employed is expressed by abscissæ and the degrees of efficiency by ordinates. Then it will appear at a glance that in a time of good trade the efficiency of the 'marginal' labourer—that is, of the worst man who just manages to retain his employment—is necessarily less than when the total demand for labour has shrunk from any cause. In the latter case the workmen discharged will for the most part be the less eligible section; and this state of things is quite independent of the true cause of the shrinkage in the demand for labour, so that while the personal defects of A may be the decisive reason why he is selected for unemployment instead of B, it does not follow that these defects are a principal or even a contributory cause of his unemployment.

It is a very complex and difficult question, only to be determined in any given case with full regard to all the circumstances, to what degree the increase or decrease of the personal efficiency of the labourer conduces to an increase or decrease in the total demand for labour, or to what degree it merely enables him to shift the burden of unemployment on to someone else. Broadly speaking, there is no doubt that the total demand for labour is to a material extent dependent on its average efficiency. For example, a quite new demand for labour would be created if it were possible to level up all the feeble-minded and the physically and morally defective members of the community to the normal level. The abnormal defects of these persons (the true unemployables) are the *vera causa* of their unemployment,

which does not in the main result from any deficiency in industrial demand, but from the fact that their services are so worthless relatively to that of the normal workman, that to all intents and purposes they may be regarded as an industrially useless surplus. Their unemployment is, therefore, emphatically not an 'insurable risk,' and they would need to be excluded from the scope of any scheme of insurance as rigorously as exceptionally bad lives are excluded from life and sickness insurance.

But if we put aside the comparatively small section of abnormals, there is ground for asserting that at all events within the great groups of trades to which I have already referred the influence of variations in efficiency among ordinary normal workmen on the total demand for labour at any given time, though by no means negligible, is not nearly so powerful as that of variations in industrial conditions which are beyond the control of the individual workman.

If, then, the insurable elements in unemployment in these trades largely predominate over the uninsurable elements, it would be comparatively simple to devise an appropriate scheme for dealing with the evil, if every separate case of unemployment could be readily assigned to its appropriate category, so that the benefits of the scheme should be exclusively available in the case of unemployment falling within the insurable category, just as a policy of marine insurance excludes in terms losses due to a number of specified causes. But in actual practice I need hardly say that any such separation of causes can only be made to a very limited extent. In the real world of industry the various elements that contribute to unemployment are inextricably intermixed. We can imagine the case of a carpenter who with equal truth might ascribe his unemployment to the competition of structural steel, to the general trade depression, to the severity of the winter, to local overbuilding, or to the defects in his own training.

There are a few, but only a few, of the causes of unemployment which can be definitely distinguished and excluded in terms from the benefit of an insurance scheme, such, for example, as holidays, strikes and lock-outs, voluntary leaving of a situation, sickness, and crime. If, then, it is necessary, as it certainly is for the success of a scheme, that it should discriminate against unemployment due either to exceptional defects or to causes within the control of the individual, this discrimination must be effected automatically in the course of the working of the scheme itself rather than by any rule professing to exclude ineligible cases from its scope.

The crucial question from a practical point of view is, therefore, whether it is possible to devise a scheme of insurance which, while nominally covering unemployment due to all causes other than those which can be definitely excluded, shall automatically discriminate as between the classes of unemployment for which insurance is or is not an appropriate remedy.

We can advance a step towards answering this crucial question by enumerating some of the essential characteristics of any unemployment insurance scheme which seem to follow directly or by necessary implication from the conditions of the problem as here laid down.

1. The scheme must be compulsory; otherwise the bad personal risks against which we must always be on our guard would be certain to predominate.

2. The scheme must be contributory, for only by exacting rigorously as a necessary qualification for benefit that a sufficient number of weeks' contribution shall have been paid by each recipient can we possibly hope to put limits on the exceptionally bad risks.

3. With the same object in view there must be a maximum limit to the amount of benefit which can be drawn, both absolutely and in relation to the amount of contribution paid; or, in other words, we must in some way or other secure that the number of weeks for which a workman contributes should bear some relation to his claim upon the fund. Armed with this double weapon of a maximum limit to benefit and of a minimum contribution, the operation of the scheme itself will automatically exclude the loafer.

4. The scheme must avoid encouraging unemployment, and for this purpose it is essential that the rate of unemployment benefit payable shall be relatively low. It would be fatal to any scheme to offer compensation for unemployment at a rate approximating to that of ordinary wages.

5. For the same reason it is essential to enlist the interest of all those engaged in the insured trades, whether as employers or as workmen, in reducing unemployment, by associating them with the scheme both as regards contribution and management.

6. As it appears on examination that some trades are more suitable to be dealt with by insurance than others, either because the unemployment in these trades contains a large insurable element, or because it takes the form of total discharge rather than short time, or for other reasons, it follows that, for the scheme to have the best chance of success, it should be based upon the trade group, and should at the outset be partial in operation.

7. The group of trades to which the scheme is to be applied must, however, be a large one, and must extend throughout the United Kingdom, as it is essential that industrial mobility as between occupations and districts should not be unduly checked.

8. A State subvention and guarantee will be necessary, in addition to contributions from the trades affected, in order to give the necessary stability and security, and also in order to justify the amount of State control that will be necessary.

9. The scheme must aim at encouraging the regular employer and workman, and discriminating against casual engagements. Otherwise it will be subject to the criticism of placing an undue burden on the regular for the benefit of the irregular members of the trade.

10. The scheme must not act as a discouragement to voluntary provision for unemployment, and for that purpose some well-devised plan of co-operation is essential between the State organisation and the voluntary associations which at present provide unemployment benefit for their members.

Our analysis, therefore, leads us step by step to the contemplation of a national contributory scheme of insurance universal in its operation within the limits of a large group of trades—a group so far as possible self-contained and carefully selected as favourable for the experiment, the funds being derived from compulsory contributions from all those engaged in these trades, with a subsidy and guarantee from the State, and the rules relating to benefit being so devised as to discriminate effectively against unemployment which is mainly due to personal defects, while giving a substantial allowance to those whose unemployment results from industrial causes beyond the control of the individual.

Is such a scheme practicable?

This is a question partly actuarial, partly administrative, and partly political, and it is, of course, quite impossible to discuss it adequately on an occasion such as this.

I may, however, say that so far as can be judged from such data as exist (and those data are admittedly imperfect and rest on a somewhat narrow basis), a scheme framed on the lines I have indicated is actuarially possible, at least for such a group of trades as building, engineering, and shipbuilding—that is to say, a reasonable scale of contributions will yield benefits substantial in amount and of sufficient duration to cover the bulk of the unemployment ordinarily met with in these trades.

The administrative difficulties of such a scheme are, of course, great, but none of these difficulties is, I think, insuperable if there be a general desire that the experiment should be made. Certainly the experience of the few foreign schemes which have broken down creates no presumption against success, for the failures have been quite clearly attributable to causes which would not operate in the case of a national scheme such as is now under discussion, especially if it were worked, as it naturally would be, in close connection with the new Labour Exchanges.

Perhaps the most difficult administrative problem would be the adjustment of the scheme, so that while its benefits are not confined to workmen for whom provision is made by voluntary associations, it would yet operate so as to encourage the work of these associations, and not to undermine and destroy them, either by competition or detailed control. The problem, however, though difficult, is one for which a solution can assuredly be found if it be the general desire that a scheme shall be brought into operation.

The remaining question is one of high policy. What importance do we as a nation attach to the policy of promoting industrial security by collective action? And what sacrifices are those interested prepared to make for such an object, and, in particular, to minimise the irregularity of working-class incomes so far as affected by irregular demand for labour? The final answer will depend not only on the general view taken of the relations of the individual and the State, and of the scope and limits of political action, but also on the relative weight attached to this particular object as compared with other objects which also have claims on public funds and energy.

The following Papers were then read :—

1. *The Price of Electricity.*
By Edward W. Cowan, *M.Inst.C.E., M.Inst.E.E.*

In this paper the adoption of certain principles by the electrical industry as a basis for the charges made for electricity supply was criticised.

A fundamental principle which the industry has established is that of charging upon the basis of *equal rate of profit* from every class of consumer. This system has many advantages from a book-keeping point of view, and is a safe system which is also comparatively simple to administer.

But the author argued that the 'equal profit' system fails in the attainment of the best economic results, because the factor of demand is ignored in such a system. The demand for electricity is of a composite character. It is a demand for light, for power, for heat, &c. The intensity of demand as between these various uses of electricity will be different; that for light generally being greater than that for power, at a given price, and so on. As it will be admitted that the greatest economic advantage will be realised when there is the closest and widest possible correspondence between the incidence of supply and the incidence of demand, it must follow that adjustment of price of supply according to the intensity of demand in the case of each class would secure a more efficient correspondence, and consequently a greater aggregate economic advantage. The difficulties in giving effect to a practical system of classified tariffs were discussed, and it was shown by reference to the successful operation of the system in railway working and in other industries that these difficulties are not insurmountable. It was also shown that electricity production for public supply is of the nature of a 'joint' production, and it was argued that, in so far as it is of that character, no separate part of the supply can be regarded as having a separate calculable cost. Examples were given in other industries of apparent anomalies in the separate prices of the component parts of a 'joint' supply. It was shown that these prices, as to their relation to each other, are influenced by the intensity of demand for each part of the joint production, and the impossibility of ignoring this influence without great economic loss was pointed out.

The adherence of electrical engineers to the 'equal profit' system was discussed, they believing that such a system is ethically right, and that any classification of prices according to the nature of demand would involve the introduction of an unfair element into the business.

The author contended that, when the conditions are analysed, it is found that there are no grounds for such a view, but that, from an ethical standpoint, classification may be resorted to without any injury or loss to any class. The gain due to such a method was shown not to be a differential gain, but a specific gain which may be shared by all classes of consumers. Further, it was shown that the 'equal profit' system cannot be entirely justified from the ethical point of view, because certain injurious results may accompany its working; and the fact that the measure of advantage is arbitrarily restricted by the system can scarcely be justified, unless the practical difficulties of classification are such that its adoption is on that account undesirable.

A diagram was given which depicted 'demand' characteristics for light, power, and heat, and also a 'cost of production' (*plus* a reasonable profit) characteristic. The aggregate demand at equal rate of profit from each class of consumer was plotted, and, with the arbitrarily selected elasticities of demand taken,

the aggregate demand is found to be 2·7 @ 2 price (for each class of supply). The effect of a 'classified' tariff was then shown, and, under the conditions taken, a price of 2 for electricity for light use, 0·8 for power use, and 0·6 for heating use, it was found that the aggregate demand is increased from 2·7 to 6, and the mean price per unit reduced from 2 to 1·13, with the same percentage of profit. This diagram does not pretend to represent actual conditions, but it was presented for the purpose of demonstrating the operation of the principle of classification.

The paper concluded with a reference to the practical import of the question at issue. It was pointed out that there is an immense potential demand for electricity for power and domestic heating and refrigeration, which could be rendered active by the sufficient lowering of price.

Without attempting to measure the practical effect of a wise classification of tariffs, the author claimed that if any economy can be realised by the system it is not right to ignore it or condemn it upon insufficient grounds. Though the economy may not be great, small price changes sometimes effect great alterations in the volume and channels of trade.

An appendix dealt with the legal aspect of the question, the author holding that 'classified' tariffs would not be held to be illegal, as the clause in the Electric Lighting Act, 1882, which enacts that 'undue preference' shall not be given, was translated from the Railway Acts, and, as is well known, classification upon the basis of value of the goods carried, quite apart from the separate cost of transporting them, is practised by all the railway companies.

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2. *India and Tariff Reform.* *By* Professor H. B. Lees Smith, *M.A.*

In this paper two subjects were discussed—(1) The Protectionist movement in India; (2) The Position of the United Kingdom under a Scheme of Preferential Tariffs with India.

(1) The Protectionist movement in India :—

Public opinion in India overwhelmingly Protectionist. The Swadeshi movement. The effect of Indian nationalism upon Protectionist sentiment. The famine problem and the demand for diversity of industry. The infant industries of India. The influence of Protection upon the industrial conservatism of India. Examination of the chief Indian industries and discussion of the effect of Protection upon them.

(2) Position of United Kingdom under a Scheme of Preferential Tariffs with India :—

Analysis of imports into India from foreign countries of which a part might, as the result of a preference, be supplied by Great Britain. Corresponding analysis of imports into Great Britain from foreign countries of which a part might, as the result of a preference be supplied by India. Would a protective tariff for the United Kingdom lead to Protection for India?

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3. *Economic Transition in India.* By Henry Dodwell, *B.A.*

India is generally acknowledged to be in a state of economic transition, but the precise meaning of this term is not fully appreciated. Hence we inquire (1) What are the relatively permanent states between which India is moving? (2) What are the causes and effects of this movement? The movement is seen in the contrast between rural and city India. The rural village is self-sufficing, the cultivator has little or no capital, the economic functions of landlord and cultivator are not yet differentiated, a money economy is not yet completely in use. The economic inefficiency resulting is paralleled in ancient and mediæval times in Europe. City India, on the other hand, is in an entirely different economic category, with its advertisements and competition, its joint-stock companies (native and European), its large accumulation of capital, banking and credit institutions, its factories and large-scale production, with a consequent wide demand for technical education.

The existence side by side of these contrasts is a unique economic phenomenon. In Europe the development from primitive to more highly developed forms has

been organic and spontaneous; in India it is mechanical and from without. Economic transition in Europe is, and has always been, evolutionary : in India, at present, it is revolutionary. Railways constitute one solvent of disparity—they affect local prices, disorganise and readjust local production, and widen markets for Indian labour. The same has been true in Western countries, but in India the solvent is drastic, sudden, and abrupt. The transition is, therefore, marked by contrast and antagonism between the wholly novel and the immemorially old. This antagonism is seen in the resistance of caste and custom in the domains of capital development and labour organisation, and is illustrated in the working of the factory system in the few industrial centres. The only period in which Europe offered even faint analogies to modern India was that of the industrial revolution, but that was not nearly so sweeping as economic changes now in operation in India.

The result is really temporary dislocation and disorder. The rapidly accumulating results of Western education, superadded to more sudden introduction of new economic organisation, is really the root of Indian unrest. Had India been a European country or under the later rule of native princes, the result would have been chaos. The present great desideratum for India is, therefore, a period of rest in which to adjust herself leisurely and gradually to new conditions not of her own seeking, but imposed on her from without.

FRIDAY, SEPTEMBER 2.

The following Papers and Report were read :—

1. *The Measurement of Profit. By* Professor W. J. Ashley, *M.Com.*

Profit is the one share in the distribution of wealth not, until very recently, subjected to statistical measurement, owing to the dearth of exact information. This information is now being furnished in increasing abundance, as a result of the adoption by business enterprise of the limited-liability joint-stock company form of organisation. Accordingly during the last decade considerable attention has been directed in Hungary and Germany to the statistical problem of the *Rentabilität* (profitableness) of investments; and finally in 1908 the Imperial Statistical Office was charged with the duty of reporting annually on 'The Business Results of German Joint-Stock Companies.' It was the purpose of this paper to give an account of the various attempts of Continental statisticians—beginning with the epoch-making work of Körösi—to define *Gewinn* (*gain* or *profit*) from the two points of view of (*a*) the companies and (*b*) the shareholders, and to disentangle the pertinent figures from company balance-sheets. It was shown that questions of statistical method are necessarily in this matter bound up with questions of economic principle. The paper ended with some observations as to the relation between the statistical results so far obtained and the doctrine of an average or usual rate of profit.

2. *The Meaning of Income. By* Professor Edwin Cannan, *M.A., LL.D.*

As commonly conceived, income is undoubtedly a sum of money; and here, as frequently elsewhere, economists have been a little too hasty in transferring the name from the sum of money to what they supposed to be the 'real' things which the sum of money only indicated.

In ordinary life, 'income' is commonly taken to mean something different from the total receipts in money of the income-receiver during a given period of time: both additions and subtractions are made.

The annual value of a house inhabited by its owner is treated as a part of his income almost invariably; the annual value of free board and lodging and services sometimes is and sometimes is not so treated; no estimate of the annual value of services rendered by the State and paid for out of taxes is ever included.

Subtractions are always made for certain amounts of outlay considered to be necessary for obtaining the income, and then the income is what remains. The fact that this process is illogical, since we cannot decide what is necessary for obtaining the income till we know the magnitude of the income, is usually overlooked. The idea at the bottom of the process seems to be so to calculate income that persons should be able to spend their whole income in satisfying their periodical wants, and yet continue to be as well off (and no better) in the future as at the present moment. If they spend more than their income they will be worse off, and if they spend less (or 'save') they will be better off, provided, of course, that what they save is well invested.

The complete and systematic carrying out of this idea is made difficult by the short and uncertain duration of life, and still more of working life. In calculating incomes from most kinds of property we set before ourselves the ideal of permanence into an indefinite futurity, whereas in calculating incomes dependent on the life of the receiver we are content to think of his life alone; and in calculating incomes derived directly from labour we are content to consider quite short periods, such as a year, and do not even attempt to 'smooth' the income over working life, nor to subtract cost of education and training.

When statisticians compute 'national incomes,' *i.e.*, the total income of all the persons living on a particular area, they add together all three sorts of income. There is ordinarily a perpetual succession of life-annuitants and of workers, so that receipts which are temporary to individuals may be permanent enough to the 'people of the country.' The total income derived from property is not a matter of simple arithmetic, nor even of elaborate accounting, but very largely a matter of mere speculation, as no man can really foresee the future, on which it depends; but it may very likely be that errors in one direction balance those in the other, so that the total may come out more nearly right than a sum obtained by any other method. It should not be forgotten, however, that the total income from property is calculated on the assumption that the number of owners will remain unchanged. It is not true that the fact that the whole of the inhabitants of an area are spending less than their aggregate income proves that the whole of the inhabitants in the future will have more income per head from property. Whether or no must depend partly on the variation of population.

Economists have assumed that the income in money represents the money value of certain commodities and services and additions to capital, which they call the 'real income'; but there is no such separate set of commodities and services and things added to capital. Income can only be ascertained by valuation. Like other conceptions dependent on valuation, it is of little or no use in dealing with 'nations' and society at large. It is not desirable to endeavour to change the meaning of the term by throwing out alterations of capital and applying it to material welfare actually enjoyed, since the term has at present a useful signification in regard to individuals, and is required in dealing with distribution.

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3. *Report on the Amount and Distribution of Income below the Income-Tax Exemption Limit.*—See Reports, p. 170.

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4. *The Trade Cycle and Solar Activity.*
By H. Stanley Jevons, *M.A.*

The chain of causation connecting the trade cycle with oscillations of solar energy may be traced through the weather and harvests. The energy received by the earth from the sun, whether in the form of radiant heat or of electrical effects, oscillates in a period of variable length, averaging about 3·6 years. Meteorologists have shown that there is in many localities a very marked variation of atmospheric temperature and pressure in the same period, which is a partial measure of an actual climatic variation, making the weather alternately favourable and unfavourable to the harvests. Statistics of crops show that the alternation is in opposite senses in regions of continental and oceanic climate

respectively, harvests being abundant in continental areas when they fail in lands bordering the oceans. Compensation is incomplete, however, because the cultivated area of continental regions now greatly exceeds that of the oceanic territories. The grand total of the world's agricultural produce varies, therefore, from year to year, sometimes probably by more than 10 per cent. Good harvests recur in the continental areas every three or four years, and they have a predominating influence on the world's trade.

Abundant harvests stimulate trade through five channels: (1) Increased demand of the agricultural classes for manufactured goods of all kinds; (2) the cheapening of food, which means greater purchasing power for all classes; (3) the decreased cost of the raw materials of many industries; (4) the increase of credit which results from the increase of wealth, and starts a general rise in prices; (5) the increase of free capital which, in conjunction with the foregoing effects, greatly stimulates the demand for materials of construction. Many exporters are well aware of the close dependence of their trade on the harvests of the countries they deal with, and the facts can be demonstrated statistically. Most striking is the close relation between the output of pig iron and the total agricultural production in the United States.

The trade cycle consists of four periods—*depression, expansion, boom, collapse*—constantly recurring. Prices, railway earnings, and total foreign trade are the best indices of the phase of the cycle. The collapse of prices is usually the most definite feature, and where credit organisation is defective it sometimes causes a financial crisis.

The dates of collapses are ascertainable definitely from 1772 on, and with great probability from 1695. They occurred in the following years: 1696, (1702), (1712), 1721, 1732, (1743), (1753), (1763), 1772, 1783, 1793, 1796, (1811), 1815, 1825, 1836, 1839, 1846, 1857, 1866, 1873, 1883, 1890, 1900, 1907. There is some doubt as to whether the collapses indicated by parentheses might not be put one year earlier; but they could not go later. These trade cycles may be grouped according to their length, under the first and second suppositions as to the dates in parentheses, as follows:—

Length of cycle in years . . .	3	4	5	6	7	8	9	10	11	12	13	14	15
Dates as above	2	1	0	1	4	0	4	7	4	0	0	0	1
Dates in parenthesis taken one year earlier . . .	2	0	2	0	4	0	1	10	4	0	0	1	0

The clustering round 3, 7, and 10 years is significant. If π represents a short period, about $3\frac{1}{2}$ years in length, it is evident that the trade cycle may be π, 2π, 3π, or even 4π The whole period 1696-1907 is 62π, and this gives 3·4 years as the average length of π. The discrepancy between this figure and 3·6 requires investigation; but the meteorological period is determined from only 40 or 50 years' observations. The fact that 7-year cycles are becoming more frequent relatively to 10- or 11-year cycles is explainable on economic grounds, because supply responds more rapidly now to altered demand.

5. *Co-operative Credit Banks.* *By* Henry W. Wolff.

The concentration of banking business in a limited number of great joint-stock banks has to a large extent destroyed that convenient occasional personal credit which private bankers gladly gave, and were in a position to give, because they were in close touch with borrowers and aware of their doings. Large joint-stock banks are in a different position, and they have a more lucrative use for their money. It has been proposed to supply the want created, which is felt in many quarters, by the formation of a distinct kind of bank, formed for such special purpose, likewise on the joint-stock principle. Such schemes, however, offer little promise of abiding remedy, since experience shows that all such banks, once they find themselves strong enough to do so, desert their original path for more remunerative business. The crux of the question lies in the shareholder's natural desire for dividend. If the potential borrower is to be helped with a certainty that such help will be forthcoming and endure, the quest of profit must

be got rid of and the principle of common service must be substituted. Sixty years' experience in hundreds of co-operative banks abroad, however, shows that this can be done with excellent effect. It has also shown that ordinary bankers, having advisedly given up this particular province of business, have nothing to apprehend from co-operative banks. The organisation of co-operative banks was explained. It was shown that they do not stand in need of a large share capital, but can very well attract the requisite funds by good business methods, so as to be able to boast that they send no legitimate claimant empty away. As an instance, the case of the *Banque Populaire* of Mentone was cited. Concluding remarks reviewed the applicability of the system to the circumstances of this country.

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6. *A Note on the Social Interest in Banking. By* F. LAVINGTON.

In a modern industrial society dispensation from a central controlling authority is obtained by the operation of the principles of specialisation and exchange, which serve to reconcile, in part, the interests of the individual and the group by making the earnings of the one dependent upon his service to the other. The reconciliation is complete only where—

(1) Competition operates freely.

(2) In the adjustment of resources returns are maximised over a long period, so that the good and evil in the methods employed do not fall outside the period considered.

(3) The organisation evolved does not contain defects which competition does not tend to eradicate.

It is maintained that the high social cost of the two banking services—the transport of capital and the provision of currency—do not imply the existence of monopoly power, and that the far-seeing policy of the banks involves no social evils in its application.

The type of organisation contains the defect of rigidity which tends against the ideal distribution of capital, partially excluding certain classes from its use. It is however well suited to provide a currency, and is adapted to undertake a currency policy which would restrict fluctuations in general prices.

The inquiry of supreme interest—that of measuring the divergence between the directions of self-interest and social material welfare—goes to show that there is in banking an exceptionally close parallelism between the two.

MONDAY, SEPTEMBER 5.

The following Papers were read :—

1. *The Fundamental Implications of Conflicting Systems of Public Aid. By* Professor S. J. CHAPMAN, *M.A.*, *M.Com.*

Two systems are sometimes contrasted : (*a*) that of distribution of relief according to *desert* and (*b*) that of distribution of relief according to *economic and social need.* This contrast does not, however, lie at the root of the present controversy. There are two schools of thinkers among those who accept the second system, and the dividing line between these schools is determined by particular beliefs or expectations with reference (1) to the nature and magnitude of the social reactions which would follow the pursuit of different policies in the dispensation of public aid and (2) to the desirability or otherwise of these reactions. It is the existence of these divergent beliefs or expectations which has caused disagreement to define itself in relation to what might be termed the three principles of (α) deferment, (β) less eligibility, and (γ) the unity of the family. The policy recommended by those who are most apprehensive about these reactions involves hardship to some persons who are reduced to distress, but this hardship they hope to minimise

by the thoroughgoing adoption of the principle of *individualising*. But the policy of their opponents also involves hardship to some in that *compulsion* is one of its integral elements. Disagreements between the two schools are brought into high relief when the population question is taken into account.

It is easier to decide what we desire with respect to the relation of the State to the course of our individual lives than to determine which of the two bodies of sociological doctrine (outlined in the paper) approximates closer to the truth.

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2. *The Poverty Figures.* *By* Professor D. H. Macgregor, *M.A.*

Our estimate of the amount of poverty in England is based upon three inquiries—those of Booth, Rowntree, and Chiozza Money.

The last of these is a national inquiry, based upon income-tax statistics. Defining the 'poor' as those who do not pay income-tax and have less than 160*l.* a year, Mr. Money finds they number 39,000,000 people, or nine-tenths of the population. But since the average family income is only 200*l.* per annum, we can scarcely take 160*l.* as indicating the limit of real distress, unless we admit that we are a poor nation on the whole. It is better simply to say that nine-tenths of the people do not reach the level of 160*l.* a year.

The inquiries of Booth and Rowntree are local and deal more especially with poverty in the sense of *distress*. It is on the basis of these inquiries that the statement is commonly made that one-third of the nation—or about 14,000,000 people—is living in real poverty. This statement has been so exploited by both political parties that it has passed into the current coin of social discussion.

As these local inquiries are only two, no national inference ought to be made from them, unless the convergence of their results is very close. It is usually thought that this is the case. My purpose is to show, on the contrary, that there is an extremely great divergence, and that it is time to protest against what is at least a great misconception.

I do not wish to question the separate results of the two inquiries. I accept it as fact that Mr. Booth found 31 per cent. of poverty and 8·4 per cent. of great poverty in London; and that Mr. Rowntree found 28 per cent. of poverty and 9.9 per cent. of great (or primary) poverty in York.

My aim is to show first that their definitions of poverty are so different that simply to compare the numerical results—28 and 31 per cent.—is out of the question; second, that when the inquiries are reduced to the same basis the results are so extremely divergent that they must be left in their separateness for the present.

First, then, what did Booth count? He tells us very distinctly that by a poor family he means one whose income is not more than 21*s.* a week; and that a 'very poor' family is one having not more than 18*s.* a week. It is purely and entirely an income test, which he himself calls 'arbitrary.' About 31 per cent. of the people in London have up to 21*s.* a week, including 8.4 per cent. who have less than 18*s.* a week. But where Booth counted one thing Rowntree counted two things. He first counted primary poverty—which means incomes of not more than 21*s.* 8*d.* a week—and of this he found 10 per cent. in York; and then he proceeded to count secondary poverty, which is a question not of income but of expenditure, and which Booth did not count at all. Of this there was 18 per cent.—much the greatest part of York poverty. It is clear, therefore, that if anything is to be compared with Booth's 31 per cent. of 21*s.* incomes it is Rowntree's 10 per cent. of 21*s.* 8*d.* incomes; and that to compare the two gross results is absurd. It is as if Booth had counted red-haired people and Rowntree fair-haired people.

Second, let the two inquiries be reduced to the same basis. How much of Rowntree's poverty is there in London and how much of Booth's poverty in York? Fortunately it is possible to find this out on the data of the two books. The number of people in York who do not earn more than 21*s.* a week is, according to a table of Rowntree's, 8½ per cent. We have thus got a more exact comparison. In the same way we can find from Booth's book that the

total amount of 'primary and secondary' poverty in London is at least 48 per cent., and is almost certainly over 50 per cent. of the people. So that, as soon as we reduce to the same definition for both cases, we get the most opposite results. What else was to be expected from a comparison of a provincial city with the greatest centre of casual labour in the world? The opposition of the results is still more striking when allowance is made for the different costs of living in the two places. When this is done the York figure which corresponds to Booth's 31 per cent. comes down from $8\frac{1}{2}$ to 3 per cent.

We get the conclusion, therefore, that of poverty in Booth's sense of the word there is 3 per cent. in York (corrected for cost of living), or $8\frac{1}{2}$ per cent. (uncorrected), against 31 per cent. in London; and of poverty in Rowntree's sense there is 28 per cent. in York and (when corrected) over 50 per cent. in London. No national inference is possible from results like that. The statement that the numbers of our people who are living in poverty is, or approximates to, 31 per cent. is not based on evidence which bears scrutiny. The numbers may be either much greater or much less than that. We need far more evidence on a uniform definition of the thing inquired into.

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3. *Production and Unemployment. By* Miss Grier.

The word 'unemployment' is too comprehensive to be definite. There are innumerable grades among the 'unemployed' as among the employed. Unemployment is due partly to industrial maladjustment, caused by want of foresight on the part of employers and employed, and partly to lack of industrial qualities among the employed and unemployed. It would only be possible entirely to avoid unemployment by perfect adjustment of the supply of (i) different kinds of goods and services to the demand for them, and (ii) different kinds of labour needed in production.

The abolition of the demand for intermittent labour would leave no alternative between regular work and destitution. This would have a 'deterrent' effect, but would not increase the general demand for labour, except in so far as it increased production. Increased production increases the possibility of employment but also the possibility of unemployment. To reduce unemployment it is not so much necessary to increase total production as to increase the value of the work of those who tend to become unemployed. Increased production on the part of low-grade workers is useless unless their number is limited. The demand for their services is apt to be inelastic. The need for greater adaptability was insisted upon and remedies were suggested.

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4. *Under-employment and the Mobility of Labour. By* J. St. G. Heath.

A study of the census returns of occupations for 1891 and 1901. Definition of economic transformations. Dislocations which take place in a particular industry through changes in demand, or through the substitution of new and cheaper factors of production, such as machinery, women, and juvenile labour. Effects of economic transformations upon adult male labour.

Attempt to estimate the effects by observing the changes in occupations between 1891 and 1901 as shown in the census returns.

Criticism of previous attempts of Mr. Booth and Mr. Beveridge.

Both have taken a single census report. Two census reports required. All those who were returned as occupied in 1891 between the ages 25-35, with the exception of those who have died or retired, will be found in the age group 35-45 ten years later, and so with the other age groups.

Table I. shows certain main orders of occupations in the census reports for 1891 and 1901.

Table I.

—	Total Population	I. General or Local Govt. of Country	III. Prof. Occupations and Services	IV. Domestic Offices	V. Commercial Occupations	VI. Conveyance	VII. Agriculture	IX. Mines and Quarries	XII. Building
Total males occupied 10 and upwards: A. 1891	8,810,703	129,260	241,245	112,975	395,535	1,035,314	1,232,313	645,003	723,043
B. 1901	10,156,976	171,687	284,915	190,459	530,685	1,351,128	1,148,028	797,800	1,007,555
C. Percentage increase of above during 10 years	15·1%	32·8	18·1	68·5	34·1	30·0	−6·9	23·6	39·0
D. Percentage of occupied males between 10 and 20 to total males occupied in 1901	18·1%	15·6	9·8	20·0	13·5	20·9	18·4	19·0	14·4
E. Total males occupied in age groups taking each age in 1891 as 100 and taking the number who remain in 1901, 10 years later, as a percentage of that	1891 1901	1901	1901	1901	1901	1901	1901	1901	1901
	15–25 100								
	25–35 100 95·9	167·3	151·8	137·3	104·5	118·5	62·7	100·4	141·6
	35–45 100 92·3	101·4	95·1	155·8	91·4	97·9	89·1	94·1	110·0
	45–55 100 85·3	80·4	86·1	119·0	85·5	88·2	91·6	87·0	97·5
	55–65 100 70·8	55·6	74·0	93·1	71·9	70·7	81·4	68·6	71·8
	65–75 47·6	32·8	54·4	63·6	46·1	42·4	59·0	38·2	55·6

—	Total Population	XIII. Wood, Furniture, Decorating	XIV. Brick, Cement, Pottery	XVII. Paper, Printing, Books, &c.	XVIII. Textiles	XIX. Dress	XX. Food, Tobacco, Drink	XXI. Gas, Water, Electricity
Total males occupied 10 and upwards: A. 1891	8,810,703	182,824	105,337	156,523	512,999	390,687	612,227	40,816
B. 1901	10,156,976	233,000	136,218	188,057	487,646	414,637	726,817	68,396
C. Percentage increase of above during 10 years	15·1%	27·4	29·3	20·1	−5	6·1	18·7	67·5
D. Percentage of occupied males between 10 and 20 to total males occupied in 1901	18·1%	17·8	24·1	22·3	25·2	16·2	16·3	4·4
E. Total males occupied in age groups taking each age in 1891 as 100 and taking the number who remain 10 years later in 1901 as a percentage of that	1891 1901	1901	1901	1901	1901	1901	1901	1901
	15–25 100							
	25–35 100 95·9	111·1	92·8	81·9	65·7	92·9	104·9	317·4
	35–45 100 92·3	101·8	98·6	90·8	78·1	86·8	99·1	154·3
	45–55 100 85·3	92·2	87·2	85·3	76·0	80·8	86·4	116·3
	55–65 100 70·8	74·4	69·2	72·2	60·9	69·8	68·9	96·4
	65–75 47·6	51·0	44·9	45·8	37·6	49·2	44·3	67·2

Table II. shows certain sub-orders where during the ten years apparently many men over twenty-five have been displaced, and where there is also apparently an excess of youths.

TABLE II.—*Children and Dislocation.*

—	Total Population			Paper	Hemp, Jute, &c.	Brass	Glass	Cotton	Wool	Machinery and changes in demand: Wheelwrights	Machinery and changes in demand: Coachmen
Percentage increase of total males occupied 10 and upwards between 1891 and 1901	15·1%			22·0	−3·5	29·6	15·5	−2·2	−14·9	4·0	14·2
Percentage of occupied males between 10 and 20 to total males occupied in 1901	18·1%			26·2	26·7	25·1	28·3	30·2	26·7	16·8	14·1
Total males occupied in age groups, taking each age in 1891 as 100 and taking the number who remain 10 years later in 1901 as percentage of that		1891	1901	1901	1901	1901	1901	1901	1901	1901	1901
	15–25	100									
	25–35	100	95·9	83·8	58·3	79·7	73·5	60·1	68·4	81·2	108·6
	35–45	100	92·3	93·2	85·4	86·0	84·0	74·7	71·8	85·4	84·2
	45–55	100	85·3	86·2	85·7	82·5	77·5	69·7	73·3	85·1	74·5
	55–65	100	70·8	70·6	75·4	66·9	60·4	52·8	62·0	72·2	60·0
	65–75		47·6	41·2	51·1	42·0	37·5	27·4	36·5	38·2	39·3

Table III. shows certain sub-orders where women have increased faster than men, and where men over twenty-five have been displaced.

TABLE III.—*Women and Dislocations.*

—	Total Male Population employed			262 Bookbinders		284 Hosiery		285 Lace		288 Carpet, Rug		312–15 Boots	
Percentage increase of total males occupied 10 and upwards between 1891 and 1901	15·1%			11·4		−24·0		−2·9		−22·6		−1·1	
Percentage of occupied males between 10 and 20 to total males occupied	18·1%			19·9		16·7		20·9		20·2		16·4	
Total males occupied in age groups taking each age in 1891 as 100 and taking the number who remain 10 years later in 1901 as a percentage of that		1891	1901	1901		1901		1901		1901		1901	
	15–25	100											
	25–35	100	95·9	76·3		65·8		70·0		57·7		83·5	
	35–45	100	92·3	84·7		71·4		79·6		64·6		83·1	
	45–55	100	85·3	78·1		69·9		74·3		68·0		80·0	
	55–65	100	70·8	70·5		59·7		63·4		55·5		70·7	
	65–75		47·6	42·5		45·7		44·2		36·9		50·3	
Out of every 1,000 of both sexes employed Women formed the following proportions	—			1891	1901	1891	1901	1891	1901	1891	1901	1891	1901
				554	603	629	713	625	653	440	517	185	210

Table IV. shows certain industries where many men between the ages 25-35 have apparently entered the industry during the ten years' interval, in addition to those who have moved up from the age group 15-25.

TABLE IV.—*Unwalled Industries.*

—	Total Population			Carmen, Carriers	Dock Labourers	Paviors and Road Labourers	Plasterers, Whitewashers, Paperhangers, Painters	Coal-heavers and Porters	Bricks, Tile Makers	Carpenters and Joiners	Gas
Percentage increase of total males occupied 10 and upwards between 1891 and 1901	15·1%			60·6	82·4	133·4	34·8	43·2	51·1	22·7	53·2
Percentage of occupied males between 10 and 20 to total males occupied	18·1%			17·0	6·6	4·7	12·7	8·9	24·2	18·3	3·9
Total males occupied in age groups taking each age in 1891 as 100 and taking the number who remain 10 years later in 1901 as a percentage of that		1891	1901	1901	1901	1901	1901	1901	1901	1901	1901
	15–25	100									
	25–35	100	95·9	159·3	248·0	404·4	145·4	188·4	111·1	103·2	298·1
	35–45	100	92·3	104·3	170·7	285·2	106·7	127·0	111·8	91·2	136·3
	45–55	100	85·3	91·6	137·2	252·2	91·2	98·8	98·3	86·6	99·4
	55–65	100	70·8	72·3	99·7	220·2	75·2	72·8	78·5	74·2	79·1
	65–75		47·6	42·7	61·1	149·7	45·1	47·0	48·8	52·4	50·7

The industries of England may be roughly divided into two groups which we will call the walled and unwalled. In the walled industries, such as those in Tables II. and III., previous training is needed, and entrance after the age of twenty-five is abnormal. In the unwalled industries little or no previous training is needed. Entrance into them after twenty-five years of age is very common. In Table IV. we have instances of unwalled industries, and also in Table I. numbers VI., XII., XIII., and XXI.

It is these same unwalled industries which, according to the Poor Law report, suffer most from under-employment and casual labour.

It may be conjectured that many men, thanks to economic transformations, are driven out of the walled industries and find refuge in the unwalled.

Surplus pools of labour are found in the unwalled industries, not because of competition, but because a surplus supply of labour finds refuge in such unwalled industries when displaced from the walled.

Relation of this theory to that of Mr. Beveridge.

Connection between boy labour and the under-employment of adult male labour.

TUESDAY, SEPTEMBER 6.

The following Papers were read :—

1. *Notes on the History of Sheffield Wages.* *By* GEORGE HY. WOOD, *F.S.S.*

The paper reviewed the course of wages in various trades in Sheffield with the object of pointing to the gaps in the information and of urging that an investigation should be made into the history of wages in Sheffield, particularly in those trades which, like file-making and cutlery, may be regarded as particular to the locality.

The course of wages in certain staple trades carried on in Sheffield has been (1883=*100*) :—

—	Puddlers	Coal Hewers	Building	Furnishing	Printing	Engineering	Weighted Average
Weights	1	1	4	1	1	3	11
1835	—	—	—	—	84	—	—
Circa 1840	87	67	—	—	94	—	78
1850	93	67	76	—	94	—	78
1855	125	86	83	—	94	73	86
1860	100	82	83	—	94	73	82
1866	118	92	93	83	94	84	92
1871	110	89	93	86	94	85	92
1874	145	134	101	97	100	94	106
1877	103	96	108	103	100	97	102
1880	107	91	103	100	100	91	98
1883	*100*	*100*	*100*	*100*	*100*	*100*	*100*
1886	96	91	101	100	100	100	99
1891	100	127	105	106	107	101	106
1896	91	118	109	106	107	102	106
1900	128	133	116	103	107	107	114
1906	113	118	116	107	114	108	113

Comparisons were made of the course of wages in the trades in Sheffield with the course of the same trades in the United Kingdom, and of the 'weighted average' compared with the course of wages in the chief industries of the country taken together, the latter comparison being as follows :—

	1850	'55	'60	'61	'71	'74	'77	'80	'83	'86	'91	'96	1900	'06
United Kingdom .	56	65	64	74	77	87	85	82	84	83	91	91	100	101
Sheffield . .	68	75	72	81	81	93	89	86	88	87	93	93	100	99

The course of wages in Sheffield as indicated by the trades considered is very similar to the course of wages in the United Kingdom, but wages in Sheffield have not advanced by so great a percentage in half a century.

There are a large number of trades mainly located in Sheffield, but for none of these is the information self-consistent. The records for the file and saw trades are examined as examples, and the writer urges that, as the evidence points to the course of wages in these trades having differed so greatly from that of wages in the great industries of the country, an investigation specially directed to filling the gaps in the information and solving the difficulties should be undertaken.

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2. *The Teaching of Economics in University Tutorial Classes.* *By* A. Mansbridge *and* R. H. Tawney.

The growth and extent of the tutorial class movement was considered. (In 1907-08, two classes with sixty members; in 1909-10, thirty-nine classes with 1,117 members; estimated in 1910-11 seventy classes with 2,000 members.) The organisation, procedure, and membership of classes were illustrated by some typical instances. The chief points to be remembered in connection with the classes by a teacher of economics are (*a*) that the classes consist entirely of adults, (*b*) that they have considerable practical experience of economic problems, and (*c*) the students' previous reading and motives for attending the class. Hence there is usually a more or less definite method of approach in the students' minds, *e.g.*, attention is concentrated on the effect of legal and economic institutions rather than on the motives of individuals; economics are treated as part of general political science; there is a tendency to emphasise 'short run' effects rather than 'long run' effects as more important to the manual worker. As to the curriculum, a good deal of attention should be given to economic history as an introduction to economic theory and modern problems; the economic theory is best treated comparatively; theories are better than theory; the importance is insisted upon of explaining chief sources of information (statistical and others), and methods of investigating practical problems. As to method pursued in classes,

the authors dealt with the free use of question and answer, of special knowledge possessed by students, and of blackboard diagrams. What is wanted is emphatically *not* lecturing but teaching which will make use as far as possible of the students' experience. The character of the work done was discussed. The main difficulties are the practical ones of overtime and unemployment.

3. *Statistics of Cotton Mill Accidents.* *By* H. VERNEY.

If the curve representing the fluctuations in the annual number of accidents occurring in connection with cotton spinning machinery be compared with that representing the consumption of cotton, which may be taken to be a rough index of the varying activity of employment in cotton mills, both being on the logarithmic scale, it is seen that, after 1900, the fluctuations in the two curves agree closely, except that the amplitude of the fluctuations in the accident curve is from two and a half to three times as great as that of the consumption curve; that is to say, when trade expands, accidents increase two and a half to three times as fast, and *vice versa*. This is what might have been expected. There is a normal accident rate corresponding to normal activity of employment in the mills. When trade becomes brisk, managers exert themselves to increase the output of the mills; the time allowed for cleaning the machinery while it is stopped is curtailed; new and inexperienced hands are taken on; and in many such ways the liability to accident is increased. On the other hand, when trade is slack, there is little 'driving'; there is not the same incentive to clean the machinery while it is running. If any hands have to be discharged it is the incompetents who go, and the rest may be put on short time. In all these ways the liability to accident is reduced.

Before 1900, however, the two curves differ from each other mainly in the upward slope of the accident curve. The continuous increase in accidents which this upward slope would indicate is largely fictitious, and is due to progressively improved reporting, accelerated and completed by the action of the Workmen's Compensation Act, 1897, which came into force in 1898, and may be supposed to have produced its full effect in this direction by 1900.

Other accidents than those occasioned by machinery occur in cotton spinning mills, but these are the more important and include the bulk of the preventable accidents. In 1907, 2,989 were reported, the number of workpeople in that year being 239,000, giving an accident rate of 1·26 per cent. for cotton spinning; for cotton weaving the rate was 0·29 per cent.; for the whole trade 0·69 per cent. That is, out of every thousand cotton operatives, 993 might have expected to work a whole year without sustaining any accidental injury sufficient to keep them away from work for one day, that being the criterion of absence in force in 1907. These figures are even more remarkable than they appear, for no less than 83 per cent. of these accidents gave rise to slight injuries only, *i.e.*, such as ought not, with proper attention, to keep the injured person away from work for longer than about three weeks. The fatal accidents are extremely few. In 1907 they numbered thirty-seven in spinning and twelve in weaving.

As to causation, it was found that 26 per cent. of the accidents reported in 1909 as having occurred in connection with cotton spinning machinery were purely accidental and unpreventable, and that 37 per cent. were due to the practice, almost confined to the cotton trade, of cleaning the machinery while it is working. Fifty per cent. of the accidents were due to the negligence of the injured person alone, negligence which in 6 per cent. of the cases could only be described as gross. In all, 68 per cent. of the machinery accidents were due to negligence. In only 5.2 per cent. of the cases was there any contravention of the Factory Acts.

As to the non-machinery accidents, which are about as numerous as those due to machinery, the enormous majority, 98 per cent., are not more than slight. They are largely due to falls, knocking the hands against hard objects and sharp corners, cuts, scratches, and so on; and most of them may be placed in the category of the purely accidental and unpreventable.

Joint Discussion with Sub-section B (Agriculture) on the Magnitude of Error in Agricultural Experiments.—See p. 587.

Section G.—ENGINEERING.

President of the Section.—Professor W. E. Dalby, M.A., M.Inst.C.E.

THURSDAY, SEPTEMBER 1.

The President delivered the following Address :—

British Railways: Some Facts and a Few Problems.

It is remarkable how few among us really realise the large part that railways play in our national life. How many of us realise that the capital invested in the railway companies of the United Kingdom is nearly twice the amount of the national debt; that the gross income of the railway companies is within measurable distance of the national income; that to produce this income every inhabitant of the British Islands would have to pay annually 3*l.* per head; that they employ

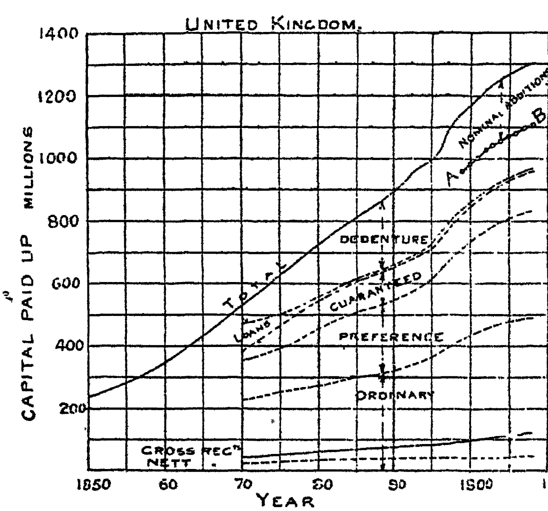

Fig. 1.

over six hundred thousand people; and that about eight million tons of coal are burnt annually in the fire-boxes of their locomotives? I hope to place before you in the short time which can be devoted to a presidential address a few facts concerning this great asset of our national life and some problems connected with the recent developments of railway working—problems brought into existence by the steady progress of scientific discovery and the endeavour to apply the new discoveries to improve the service and to increase the comfort of the travelling public.

A great deal of interesting information is to be found in the Railway Returns issued by the Board of Trade. I have plotted some of the figures given, in order to show generally the progress which has been made through the years, and at the same time to exhibit the rates of change of various quantities in comparison with one another.

Consider in the first place what the railways have cost the nation. This is represented financially at any instant by the paid-up capital of the companies. The total paid-up capital in 1850 was 240 millions sterling. In 1908 this amount had increased to 1,310 millions. The curve marked 'Total' in fig. 1 shows the total paid-up capital plotted against the year. It will be noticed that the increase per annum is remarkably regular up to about 1896 and is at the rate of not quite 100 millions per annum. After this date the capital increases at a somewhat greater rate, but in 1900 the rate drops with a tendency to a gradually decreasing value. Part of the increase immediately after 1896 is, however, due

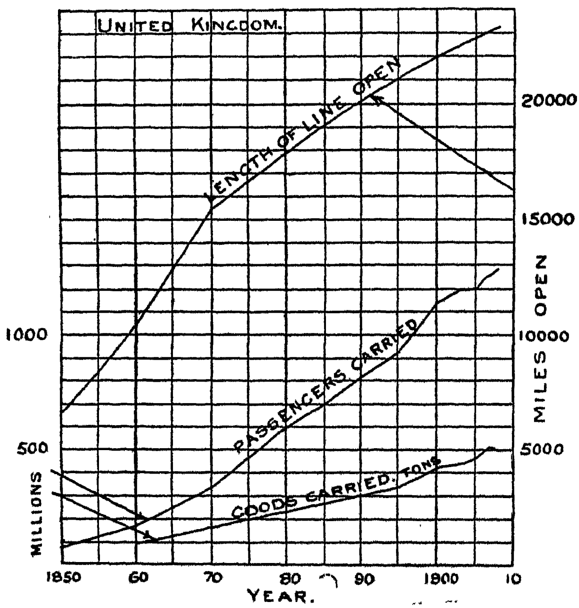

FIG. 2.

to nominal additions to the capital. The extent to which this process of watering the stock has been carried is indicated over the period 1898 to 1908 by the curve A B. In the year 1908 the nominal additions to capital amounted to 196 millions of pounds.

Curves are also plotted showing the amounts of the different kinds of stock making up the total. It will be noticed that the ordinary stock is a little over one-third of the total paid-up capital in 1908—viz., 38 per cent. In 1870 it was about 43 per cent.

The lower curve on the diagram shows the gross receipts, which amounted to 120 millions of pounds in 1908. The dotted line indicates the net revenue after deducting from the total receipts the working expenditure. This, for 1908, was 43½ millions, corresponding to 3·32 per cent. of the total paid-up capital. If the net receipts are reckoned as a percentage of the paid-up capital after deducting the nominal additions the return is increased to 3.9 per cent. These figures practically represent the average dividend reckoned in the two ways for the year 1908.

Fig. 2 shows by the upper curve the number of miles open for traffic plotted

against the year. This curve indicates great activity of construction during the period 1850 to 1870, with a regular but gradually decreasing addition of mileage from year to year afterwards.

At the end of 1908 there were 23,205 miles open, corresponding to 53,669 miles of single track, including sidings. Of this, 85 per cent. was standard 4 feet $8\frac{1}{2}$ inches gauge, 12·3 per cent. 5 feet 3 inches, and 2·2 per cent. 3 feet gauge. The remainder was made up of small mileages of 1 foot $11\frac{1}{2}$ inches, 2 feet 3 inches, 2 feet 4 inches, 2 feet $4\frac{1}{2}$ inches, 2 feet, 2 feet 9 inches, 4 feet, and 4 feet 6 inches gauges.

The two lower lines of the diagram show respectively the number of passengers carried and the tons of goods carried from year to year.

The curves of mileage, passengers carried, and goods carried increase regularly with the increase of capital, indicating that up to the present time the possibility of remunerative return on capital invested in railway enterprise in this country is not exhausted. It is true that there is a maximum of goods carried in the year 1907; but the sudden drop in the curve between the years 1907 and 1908 suggests

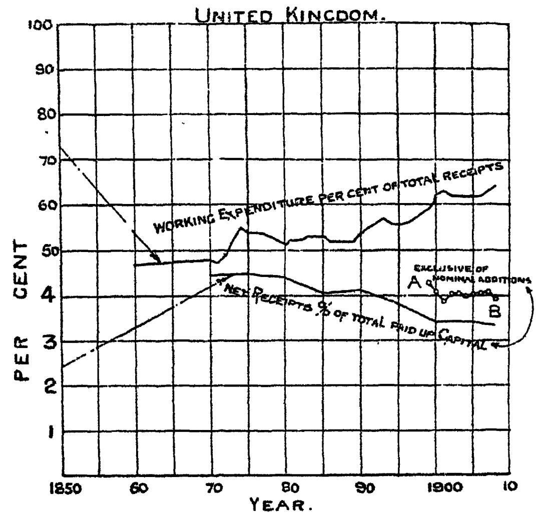

FIG. 3.

that the drop is only of a temporary character, and there is every reason to believe that the curve will resume its upward tendency with time. In 1908 the railways of the United Kingdom carried 1,278 millions of passengers, exclusive of season-ticket holders, and 491 million tons of goods; the quantity of goods carried in 1907 was nearly 515 millions of tons. It is curious that very approximately the companies carry per annum one passenger and about 0·4 ton of goods for every pound sterling of paid-up capital.

The proportion of the gross receipts absorbed in carrying out this service is shown by the upper curve of fig. 3. The proportion has increased, on the whole regularly, from 47 per cent. in 1860 to 64 per cent. in 1908.

The lower curve shows the net receipts as a percentage of the paid-up capital. From 1899 onwards the curve AB shows the net receipts reckoned on the paid-up capital exclusive of the nominal additions. It will be observed that the net receipts have not declined more than half a per cent. since 1870, notwithstanding the increase in working expenditure.

Fig. 4 indicates the cost of working the traffic calculated in terms of the train-mile, no data being available regarding the actual work done as represented by

the ton-mile or the passenger-mile. In some respects the train-mile is the fairest way of comparing costs, because when a train is running, whether it is full or empty, the same service must be performed by the majority of the departments.

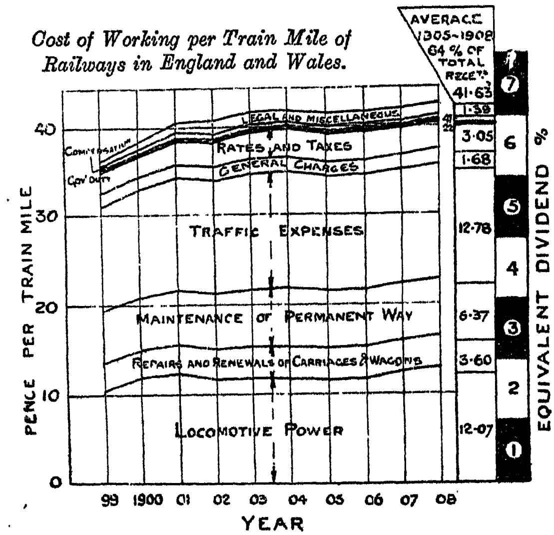

FIG. 4.

The curves bring out clearly that the proportion of the total expenditure per train-mile absorbed by these several services remains fairly constant over a series of years. To the right is exhibited the average for the four years 1905 to 1908. The figures are also reproduced in the following table :—

TABLE I.

Average Working Costs per Train-mile of the Railways in England and Wales taken over the Years 1905 *to* 1908.

	Pence per train-mile.
Locomotive power	12·07
Repairs and renewals of carriages and waggons	3·60
Maintenance of permanent-way	6·37
Traffic expenses	12·78
General charges	1·68
Rates and taxes	3·05
Government duty	0·22
Compensation	0·47
Legal and miscellaneous	1·39
Total	41·63

Locomotive power absorbs an amount about equal to the traffic expenses; and companies actually pay in rates and taxes a sum nearly equal to the whole amount required to maintain the rolling-stock in an efficient state.

To the right is shown a scale the divisions of which represent an amount estimated in pence per train-mile corresponding to 1 per cent. of the average dividend. This shows that if the whole of the locomotive power could be obtained for nothing, the average dividend would only be increased by 1¾ per

cent. Reckoned on the ordinary stock alone, however, the increase would be about three times this amount.

It may be of interest at this stage to compare the financial position and the cost of the working of railways in their earlier days with the state of things now. For this purpose the position of the old London and Birmingham Railway is compared with the position of the London and North Western Railway, the system into which it has grown. The years selected are 1840 and 1908.

I have taken out the cost per mile of working the traffic of the London and Birmingham Railway from some accounts given in Winshaw's 'Railways.' The details are grouped somewhat differently in the list just given, but in the main the various items may be compared.

The number of train-miles on the London and Birmingham Railway recorded for the year January to December, 1839, is 714,998. The accounts given are for the year June 1839 to June 1840. The mileage record is thus not strictly comparable with the expense account, but it may be regarded as covering the same period with sufficient accuracy for our purpose.

The costs work out as follows :—

TABLE II.

Cost per Train-mile for the Year ending June 1840, *London and Birmingham Railway.*

	Pence per mile.
Locomotive power	23·2
Maintenance of way	27·2
Traffic expenses, including repairs to waggons	25·9
General charges, including legal charges	4·5
Rates and taxes	4·5
Government duty	7·65
Accident account	0·35
Total	93·30

The receipts amounted to 231*d.* per train-mile. Hence the working expenditure was 40 per cent. of the gross receipts.

The gross receipts for the year ending June 30, 1840, were 687,104*l.*, which, after deducting charges for loans, rents, and depreciation of locomotives, carriages, and waggons, enabled a dividend of 9¼ per cent. to be paid on the ordinary stock.

There are two noteworthy facts in these old accounts. First, the allowance for depreciation on the rolling-stock of nearly 4 per cent. of the receipts. Secondly, the fact that the cost of working the traffic is given per ton-mile. This method of estimating the cost of working has gradually fallen into desuetude on British railways. One company only at the present time records ton-mile statistics. Quite recently (in 1909) the committee appointed by the Board of Trade to make inquiries with reference to the form and scope of the accounts and statistical returns rendered by the railway companies under the Railway Regulation Acts have had the question of ton-mile and passenger-mile statistics under consideration. There was considerable difference of opinion concerning the matter, and in the end the committee did not recommend that the return of ton-mile and passenger-mile statistics should be made compulsory on the railway companies.

Returning to the London and Birmingham Railway accounts, the actual figures given by Mr. Bury, the locomotive engineer, were, for the year ending December 1839 :—

Passenger Trains.—Ton-miles, 21,159,796, giving an average of 542,533 ton-miles per engine at 0·86 lb. of coke per ton-mile costing 0·17*d.*

Goods Trains.—17,527,439 ton-miles, giving an average of 584,247 per engine at 0·57 lb. of coke per ton-mile costing 0·11*d.* per ton-mile.

Table III. shows various amounts and quantities in comparison with one another. Beneath the actual figures are placed proportional figures, the London and Birmingham item being in every case denoted by unity.

TABLE III.

Comparison of Capital, Receipts, Miles Open, Train-miles, and Cost of Working between the London and Birmingham Railway for the Year ending June 1840 *and the London and North Western Railway for the Year ending December* 1908.

	Stock and Share Capital		Loans and Debentures		Total	Gross Receipts
	£	Interest per cent.	£	Interest per cent.	£	£
L. & B. Ry., 1840	3,125,000	$9\frac{3}{4}$	2,125,000	$4\frac{5}{8}$	5,250,000	687,000
L. & N. W. Ry., 1908	85,861,760	5 app. average on all types of stock	39,175,374	3 average	125,037,134	15,515,334
L. & B. Ry., 1840	1		1		1	1
L. & N. W. Ry., 1908	27·5		18·4		24	22·6

	Miles Open in Equivalent Single Track	Train-miles Run	Receipts per Train-mile	Cost of Working per Train-mile	Expenditure to Gross Receipts per cent.
L. & B. Ry., 1840	250	714,998	231 pence	93 pence	40
L. & N. W. Ry., 1908	5,406	48,732,644	$76\frac{1}{2}$ „	50 „	65
L. & B. Ry., 1840	1	1	1	1	1
L. & N. W. Ry., 1908	21·6	68·3	0·33	0·54	1·62

The comparison brings out some curious facts. For instance, it will be noticed that the gross receipts of the London and North Western Railway in 1908 were twenty-two and a half times as much as those of the London and Birmingham Railway in 1840, and that the track mileage open was about twenty-two times as great. The money earned per mile of track open is thus practically the same after a lapse of seventy years. To earn the same amount per mile of track open, however, the trains of the London and North Western Railway had in 1908 to run 68·3 times the number of train-miles that the trains of the London and Birmingham Railway ran in 1840. That is to say, in order to earn a sovereign a London and North Western train has now to run three times the distance which it was necessary for a London and Birmingham train to run to earn the same amount.

Another point to notice is that although the mileage and the receipts per mile of track open have each increased in the same proportion, yet the capital has increased at a greater rate, being on the total amount twenty-four times as much as in 1840, and the stock and share capital has increased twenty-eight times. So that with the necessity of running three times the train-mileage to obtain the same return per mile of track open there runs the obligation to pay interest on an ordinary stock which has been increased in a greater proportion than the mileage and in a greater proportion than the earning power of the line. Lower dividends are therefore inevitable. The cost of working per train-mile has decreased gradually to about half its value in 1840, but at the same time the receipts per train-mile have dwindled to one-third of the amount in 1840.

These figures show that a more conservative system of financing the railways might have been adopted in the earlier days with advantage. If when the receipts per train-mile were larger, a proportion of the revenue had been used annually for the construction of new works and for the provision of new rolling-stock instead of raising fresh capital for everything in the nature of an addition to the railway, the companies would to-day have been in a position to regard with equanimity the increasing cost of working.

It is too late in the day to recover such a strong financial position, but even now on many lines a larger proportion of the revenue could be sunk in the line with great ultimate advantage to the financial position.

The Problem of the Locomotive Department.

During the last twenty years the demand on the locomotive has steadily increased. The demand has been met, though with increasing difficulty, owing to the constructive limitations imposed by the gauge. The transference of a train from one place to another requires that work should be done continuously by the locomotive against the tractive resistance. The size of the locomotive is determined by the rate at which this work is to be done. If T represents the tractive resistance at any instant, and V the speed of the train, then the rate at which work is done is expressed by the product TV. The pull exerted by the locomotive must never be less than the resistance of the whole train considered as a dead load on the worst gradient and curve combination on the road, and it can never be greater than about one-quarter of the total weight on the coupled wheels of the engine.

Again, the tractive pull of the engine may be analysed into two parts—one the pull exerted to increase the speed of the train, the other the pull required to maintain the speed when once it has been reached. For an express train the number of seconds required to attain the journey speed is so small a fraction of the total time interval between the stops that the question of acceleration is not one of much importance. But for a local service where stops are frequent the time required to attain the journey-speed from rest is so large a fraction of the time between stops that this consideration dominates the design of the locomotive and, in fact, makes it desirable to substitute the electric motor for the locomotive in many cases.

An accurate estimate of the rate at which work must be done to run a stated service can only be made if there are given the weight of the vehicles in the train, the weight of the engine, the kind of stock composing the train, the speed and acceleration required at each point of the journey and a section of the road; and, in addition to this, allowance must be made for weather conditions.

A general idea of the problem can, however, be obtained by omitting the consideration of acceleration, gradients, and the unknown factor of weather conditions, considering only the rate at which work must be done to draw a given load at a given speed on the level. Even thus simplified the problem can be solved only approximately, because, although the tractive resistance of a train as a whole is a function of the speed, the tractive resistance per ton of load of the vehicles and per ton of load of the engine differ both in absolute value and in their rates of change for a stated speed, and, further, the ratio between the weight of the vehicles and the weight of the engine is a very variable quantity.

For our purpose, however, it will be sufficiently accurate to assume that the resistance of the whole train, expressed in pounds per ton, is given by the formula

$$T = 5\tfrac{1}{3} + \frac{V^2}{256}$$

It follows that the horse-power which must be developed at the driving-wheels to maintain a speed of V miles per hour on the level with a train weighing W tons is

$$HP = W\left\{\frac{V}{70} + \frac{V^3}{96{,}000}\right\}$$

Fig. 5 shows curves of horse-power plotted from this equation for various weights of train. From this diagram a glimpse of the problem confronting locomotive engineers at the present day can readily be obtained.

To illustrate the point consider the case of the Scotch express on the West Coast route.[1] This is an historic service and goes away back to 1844, in which year the first train left Euston for Carlisle, travelling by way of Rugby, Leicester, York, and Newcastle, and occupying 15¼ hours. It was not until 1847, however, that there was a through service to Edinburgh *viâ* Berwick.

In September 1848 the West Coast service for Edinburgh was established by way of Birmingham and Carlisle, the timing being 8 hours 55 minutes to Carlisle, and 12 hours to Edinburgh.

In September 1863 the starting time from Euston was fixed at 10 A.M., and in 1875 the train ran *viâ* the Trent Valley between Rugby and Stafford, thus cutting out Birmingham and shortening the journey to Carlisle from 309 miles to 299 miles, the timing being 7 hours 42 minutes to Carlisle, and 10 hours and 25 minutes to Edinburgh. The speed has gradually been increased, and in 1905

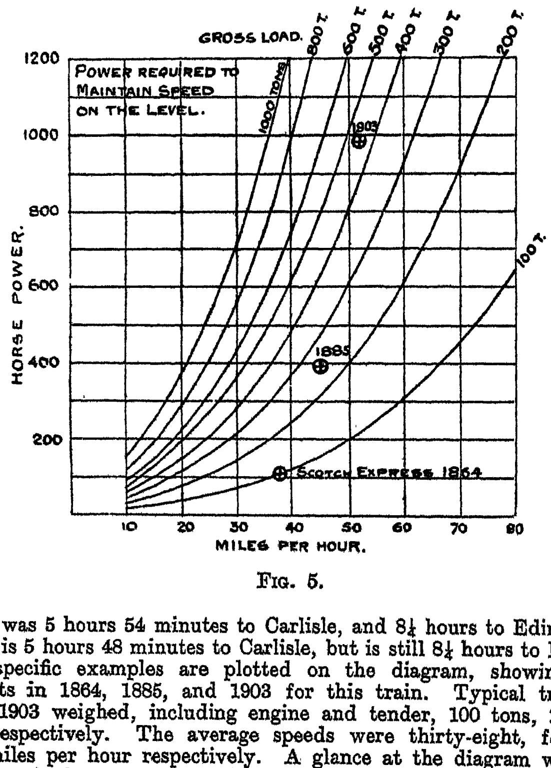

FIG. 5.

the timing was 5 hours 54 minutes to Carlisle, and 8¼ hours to Edinburgh. Now the timing is 5 hours 48 minutes to Carlisle, but is still 8¼ hours to Edinburgh.

Three specific examples are plotted on the diagram, showing the power requirements in 1864, 1885, and 1903 for this train. Typical trains in 1864, 1885, and 1903 weighed, including engine and tender, 100 tons, 250 tons, and 450 tons respectively. The average speeds were thirty-eight, forty-five, and fifty-two miles per hour respectively. A glance at the diagram will show that the power required to work this train was about 100 horse-power in 1864, 400 horse-power in 1885, and 1,000 horse-power in 1903.

It must not be supposed that the increase in the weight of the train means a proportionate increase in the paying load. Far from it. On a particular day in 1903, when the total weight of the Scotch express was 450 tons approximately, the weight of the vehicles was about 346 tons. There were two dining-cars on the train, and the seating accommodation, exclusive of the seats in the dining-

[1] I am indebted to Mr. Bowen Cooke for particulars of the Scotch Express Service.

cars, was for 247 passengers, giving an average of 1·4 ton of dead load to be hauled by the engine per passenger assuming the train to be full. In the days before corridor stock and dining-cars were invented the dead load to be hauled was about a quarter of a ton per passenger for a full train.

In a particular boat special, consisting of two first-class saloons, one second and one third class vehicles, one first-class dining-car, one second and third class dining-car, one kitchen-car, and two brake-vans, seating accommodation was provided, exclusive of the dining-cars, for 104 passengers, and the dead load to be hauled averaged 2·72 tons per passenger. Notwithstanding this increase in the dead load of luxurious accommodation, the fares are now less than in former days on corresponding services. Similar developments have taken place in almost every important service, and new express services are all characterised by heavy trains and high speeds.

Characteristic Energy-curves of Steam Locomotives.

This steadily increasing demand for power necessarily directs attention to the problem, What is the maximum power which can be obtained from a locomotive within the limits of the construction-gauge obtaining on British railways? The answer to this can be found without much ambiguity from a diagram which I have devised consisting of a set of typical characteristic energy-curves to represent the transference and transformation of energy in a steam locomotive, an example of which is given in fig. 6. While examining the records of a large

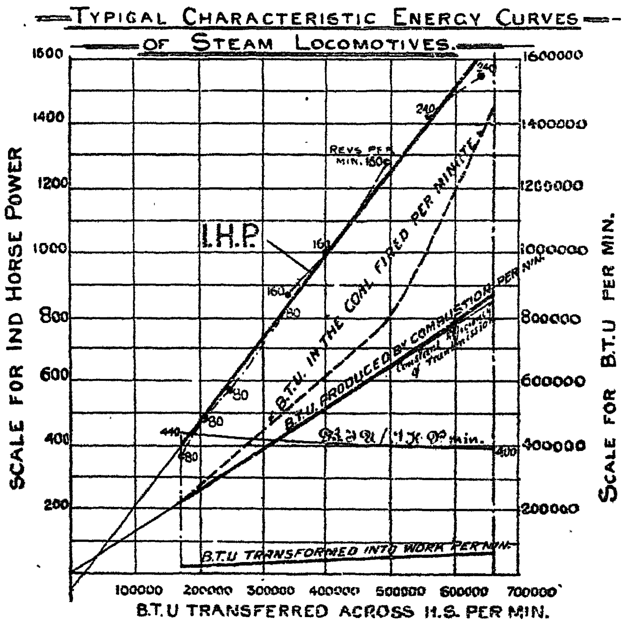

FIG. 6.

number of locomotive trials, I discovered that if the indicated horse-power be plotted against the rate at which heat energy is transferred across the boiler-heating surface the points fall within a straight-line region, providing that the regulator is always full open and that the power is regulated by means of the reversing-lever—that is to say, by varying the cut-off in the cylinders. It is assumed at the same time, of course, that the boiler-pressure is maintained

constant. I have recently drawn a series of characteristic energy-curves for particular engines, and these are published in *Engineering*, August 19 and 26, 1910. A typical set is shown in fig. 6.

The horizontal scale represents the number of British thermal units transferred across the boiler-heating surface per minute. This quantity is used as an independent variable. Plotted vertically are corresponding horse-powers, each experiment being shown by a black dot on the diagram. The small figures against the dots denote the speed in revolutions of the crank-axle per minute. Experiments at the same speed are linked by a faint chain dotted line. A glance at the diagram will show at once how nearly all the experiments fall on a straight line, notwithstanding the wide range of speed and power.

The ordinates of the dotted curve just below the i.h.p. curve represent the heat energy in the coal shovelled per minute into the fire-box—that is, the rate at which energy is supplied to the locomotive. The thick line immediately beneath it represents the energy produced by combustion. The vertical distance between these two curves represents energy unproduced, but energy which might have been produced under more favourable conditions of combustion. Some of the unproduced energy passes out of the chimney-top in carbon monoxide gas, but the greater proportion is found in the partially consumed particles of fuel thrown out at the chimney-top in consequence of the fierce draught which must be used to burn the coal in sufficient quantity to produce energy at the rate required. The rate of combustion is measured by the number of pounds of fuel burnt per square foot of grate per hour. In land practice with natural draft 20 lb. of coal per square foot of grate per hour is a maximum rate. In a locomotive the rate sometimes reaches 150 lb. per square foot per hour. In the diagram shown the maximum rate is about 120 lb. per square foot, and the dotted curve begins to turn upwards at about 70 lb. per square foot per hour. The vertical distance between the curves shows what has to be paid for high rates of combustion.

I found that in almost every case the curve representing the energy actually produced by combustion differed very little from a straight line, passing through the origin, showing that at all rates of working the efficiency of transmission is approximately constant. That is to say, the proportion of the heat energy actually produced by combustion in the fire-box which passes across the boiler-heating surface per minute is nearly constant and is therefore independent of the rate of working.

The lowest curve on the diagram represents the rate at which heat energy is transformed into mechanical energy in the cylinders of the locomotive. It seems a small rate in proportion to the rate at which heat energy is supplied to the fire-box, but it is not really so bad as it looks, because the engine actually transformed 60 per cent. of the energy which would have been transformed by a perfect engine working on the Rankine cycle between the same limits of pressure. The engine efficiency is represented in a familiar way by a curve labelled 'B.T.H. per i.h.p. minute.' It will be seen that the change of efficiency is small, notwithstanding large changes in the indicated horse-power.

The diagram indicates that the indicated horse-power is practically proportional to the rate at which heat is transferred across the boiler heating-surface, and as this is again proportional to the extent of the heating-surface, the limit of economical power is reached when the dimensions of the boiler have reached the limits of the construction-gauge, the boiler being provided with a fire-grate of such size that, at maximum rate of working, the rate of combustion falls between 70 and 100 lb. of coal per square foot of grate per hour. A boiler of large heating-surface may be made with a small grate necessitating a high rate of combustion to obtain the required rate of heat-production. Then, although a large power may be obtained, it will not be obtained economically.

Returning now to the consideration of the type of locomotive required for a local service with frequent stops, the problem is to provide an engine which will get into its stride in the least time consistent with the comfort of the passengers. The average speed of a locomotive on local service is low. The greater part of the time is occupied in reaching the journey speed, and the brake must then often be applied for a stop a few moments after the speed has been attained. In some cases the stations are so close together that there is no period between acceleration and retardation. Without going into the details of the calculation I

may say that to start from rest a train weighing, including the engine, 300 tons, and to attain a speed of thirty miles per hour in thirty seconds, requires about 1,350 i.h.p. During the period of acceleration the engine must exert an average tractive pull of nearly fifteen tons.

Mr. James Holden, until recently locomotive engineer of the Great Eastern Railway, built an engine to produce an acceleration of thirty miles per hour in thirty seconds with a gross load of 300 tons. The engine weighed 78 tons, and was supported on ten coupled wheels each 4 feet 6 inches diameter. There were three high-pressure cylinders, each 18½ inches diameter and 24 inches stroke. A boiler was provided with 3,000 square feet of heating surface and a grate of 42 square feet area. Boiler pressure, 200 pounds per square inch. This engine practically reached the limit of the construction-gauge.

An acceleration of thirty miles per hour in thirty seconds is considerably below what may be applied to a passenger without fear of complaint. But it is clear that it is just about as much as a locomotive can do with a train of reasonable weight. Even with a gross load of 300 tons nearly one-third of it is concentrated in the locomotive, leaving only 200 tons to carry paying load. The problem of quick acceleration cannot therefore be properly solved by means of a steam locomotive. But with electric traction the limitations imposed on the locomotive by the construction-gauge and by the strength of the permanent way are swept away.

The equivalent of the boiler power of a dozen locomotives can be instantaneously applied to the wheels of the electric train, and every axle in the train may become a driving axle. Thus the whole weight of the stock, including the paying load, may be utilised for tractive purposes. If, for instance, the train weighed 200 tons, then a tractive force equal to one-fifth of this, namely, forty tons, could be exerted on the train, but uniformly distributed between the several wheels, before slipping took place. The problem of quick acceleration is therefore completely solved by the electric motor.

Electric Railways.

December 18, 1890, is memorable in the history of railway enterprise in this country, for on that date the City and South London Railway was opened for traffic, and the trains were worked entirely by electricity, although the original intention was to use the endless cable system of haulage. This line inaugurated a wonderful system of traction on railways in which independent trains moving at different speeds at different parts of the line are all connected by a subtle electric link to the furnaces of one central station.

Since that epoch-marking year electric traction on the railways of this country has made a gradual if somewhat slower extension than anticipated. But electrically operated trains have in one branch of railway working beaten the steam locomotive out of the field and now reign supreme—that is, in cases, as indicated above, where a quick frequent service is required over a somewhat short length of road. The superiority of the motor over the steam locomotive, apart from questions of cleanliness, convenience, and comfort, lies in the fact that more power can be conveyed to the train and can be utilised by the motors for the purpose of acceleration than could possibly be supplied by the largest locomotive which could be constructed within the limits of the construction-gauge. There are many other considerations, but this one is fundamental and determines the issue in many cases.

A few facts relating to the present state of electric railways in the United Kingdom may prove of interest. At the end of 1908 there were in the United Kingdom 204 miles of equivalent single track worked solely by electricity and 200 miles worked mainly by electricity, corresponding to 138 miles of line open for traffic. Of this 102 miles belong to the tube railways of London and 201 miles to the older system formed by the District and the Metropolitan Railways and their extensions.

It is not an easy matter to ascertain exactly how much capital is invested in these undertakings for the purpose of electric working alone, since some of the lines originally constructed for a steam locomotive service have been converted to electric working. On the converted lines there is the dead weight of capital corresponding to the locomotive power provided before electrification took place.

The capital invested in the 102 miles of tube railways in London is a little over 25,000,000*l*.

The total number of passengers carried (exclusive of season tickets) on the 138 miles of electrical track during the year 1908 was nearly 342 millions, being roughly one-third of the total number of passengers carried on all the railways of England and Wales during the same period.

The average cost of working this traffic is 22·3*d*. per train-mile. This figure includes the service of the lifts, which is presumably returned with the traffic expenses. The charges work out in this way :—

TABLE IV.

Average Working Cost per Train-mile of the Electric Railways worked wholly or mainly by Electricity in England and Wales for the Year 1908.

	Pence per train-mile.
Locomotive power	8·40
Repairs and renewals of carriages and waggons	1·50
Maintenance of permanent way	2·40
Traffic expenses	5·22
General charges	1·52
Rates and taxes	2·36
Government duty	0·088
Compensation	0·116
Legal and miscellaneous	0·75
Total	22·35

The corresponding total receipts were 38·65*d*. per train-mile. The working expenses are thus 58 per cent. of the total receipts. Comparing this with the figures given above for the whole of the lines in England and Wales, it will be seen that the cost for locomotive power on the electric railways appears to be about two-thirds of the cost on steam lines per mile run, the cost for repairs and renewals of carriages and waggons about one-half, and the cost for traffic expenses about one-half.

The two kinds of working are not, however, strictly comparable, as all the conditions of traffic in the two cases are different and the length of the electric lines is relatively so small that the problems which arise out of the transmission of electric power over long distances are excluded. The traffic expenses and the cost of repairs and renewals of carriages and waggons, general charges, &c., are practically independent of the kind of power used for locomotive purposes, and, moreover, the difference in weight of electric trains and the steam-hauled trains is on the average so great that no comparison can be instituted without ton-mile statistics.[1]

Method of Working.

With two exceptions the method of working the electrified lines of this country is in the main the same. A third conductor rail is laid on insulators fixed to the ordinary track sleepers, and is maintained throughout the whole of its length at as nearly as possible a pressure of 600 volts, except in a few cases where the pressure is 500 or 550 volts. Collecting shoes sliding along the rails are fixed to the trains, and through them current is supplied to the armatures fixed to or geared with the axles. The current flows through the armatures back to the stations or sub-stations through the running rails, which are bonded for the purpose, or sometimes through a fourth rail carried on insulators fixed to the track sleepers as in the cases of the District and Metropolitan Railways.

Differences in the equipment arise out of the geographical necessities of the distribution. For a short line the power is produced at a central station and is

[1] Much valuable information regarding the cost of converting the line between Liverpool and Southport from steam to electric working will be found in Mr. Aspinall's presidential address to the Institution of Mechanical Engineers.

	City and South London	Liverpool Overhead
Date opened	Dec. 18, 1890	Feb. 1893
Length of line, in miles, on Dec. 31, 1908; equivalent double track	7·25	6·5
Gauge	4 feet 8½ inches	4 feet 8½ inches
Average distance between stations, in miles	0·4	0·38
Average schedule speed, in miles per hour	15	19
Voltage, at conductor rail	500	500
System	3rd rail	Insulated 3rd and 4th rails
Power produced at	500 and 1,000 volts D.C.	1,100 volts D.C.
Distribution	3-wire and 5-wire system; D.C.; motor generators, in 2 sub-stations	Converted to 500 volts at sub-stations
H.P. of generating station	5,000	3,000
Trains	Electric locomotive and vehicles	Motor cars and trailers
Paid-up capital, including Loans and Debenture Stock	£2,973,875	£861,442
Total receipts, 1908	£175,199	£75,035
Net receipts	£91,526	£15,365
Expenditure per cent. of total receipts	48 per cent.	80 per cent.

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TABLE V.

Some Particulars of the Electric Railways in the United Kingdom, 1910.

Waterloo and City	Central London	Mersey Railway	Great Northern and City	L. and Y. Liverpool and Southport	N.E.R. Tynemouth Lines	Metropolitan Railway, Inner Circle. Baker Street to Harrow and Uxbridge	Great Western, Metropolitan, and West London Junction Lines	District Railway	Baker Street and Waterloo	Charing Cross, Euston, and Hampstead	Great Northern, Piccadilly and Brompton	Midland. Lancaster, Morecambe, Heysham	London, Brighton, and South Coast
Aug. 1898	July 1900	May 1903	Feb. 1904	March 1904	Spring, 1904	Jan. 1905	Nov. 1906	1903–1905	1906	1907	1906	1908	Dec. 1909
1·5	6·3	4·6	3·4	33	41	30	4·7	24·3	4·23	7 75	9 23	9	8·
4 feet 8½ inches	4 feet 8½ inches	4 feet 8½ inches	4 feet 8½ inches	4 feet 8½ inches	4 feet 8½ inches	4 feet 8½ inches	4 feet 8½ inches	4 feet 8½ inches	4 feet 8½ inches	4 feet 8½ inches	4 feet 8½ inches	4 feet 8½ inches	4 feet 8½ inches
1·5	0·45	0·74	0·67	1·25	1·25	1·25	0·57	0·59	0·5	0·5	0·4	3·25	0·87
18	15·5	19	15	30	22	22	16	15·7	14	14	14	22 and 34	23
500	550	600	550	600	600	600	600	600	600	600	600	6,600	6,600
3rd rail	3rd rail	3rd and 4th rails	Insulated 3rd and 4th rails	Insulated 3rd rail, uninsulated 4th rail	3rd rail	Insulated 3rd and 4th rails	Insulated 3rd and 4th rails	Insulated 3rd and 4th rails	Insulated 3rd and 4th rails	Insulated 3rd and 4th rails	Insulated 3rd and 4th rails	Overhead	Overhead
500 volts D.C.	5,000 volts, 3-phase	650 volts D.C.	575 volts D.C.	7,500 volts, 3-phase, A.C.	5,500 volts, 3-phase, and supplied to Company's sub-stations by New-castle-on-Tyne Electric Supply Co.	11,000 volts, 3-phase, 33⅓ alternations	6,600 volts, 3-phase, 60 alternations	All supplied from Lots Road Central Station, Chelsea 11,000 volts				460 volts D.C., and converted by motor generators to single-phase at 6,600 volts, 25 cycles	6,600 volts, single-phase, 25 alternations
By feeders direct to 3rd rail	Transformed, and converted to D.C. by rotary converters, in sub-stations	By feeders to 3rd rail	By feeders to 3rd rail	Transformed in sub-stations to 600 volts D.C.	Transformed in sub-stations to 600 volts D.C.	D.C. distribution from motor generators in sub-stations	Transformed, and converted to D.C. by motor generators	D.C. distribution from rotary converters in sub-stations				Direct to trolley wire	Direct to trolley wire
1,800	9,500	5,000	4,600	13,000	—	25,500	8,000	60,000				940	—
Motor cars and trailers	Motor cars and trailers	Motor cars and trailers	Motor cars and trailers	Motor cars and trailers	—	Motor cars and trailers	Motor cars and trailers	Motor cars and trailers				Motors and trailers	Motor cars and trailers
—	£3,926,000	£3,589,712	£2,048,016	—	—	—	—	—	£3,161,600	£4,957,000	£6,544,400	—	—
£31,669	£371,930	£103,977	£85,305	—	—	—	—	—	£169,884	£182,950	£290,999	—	—
£13,470	£185,456	£29,133	£40,205	—	—	—	—	—	£79,768	£69,215	£143,547	—	—
57 per cent.	50 per cent.	72 per cent.	53 per cent.	—	—	—	—	—	53 per cent.	62 per cent.	51 per cent.	—	—

distributed by feeders to the conductor rail direct. For longer lines power is produced at higher voltage (11,000 volts in the case of the District Railway), and is then distributed to sub-stations conveniently placed along the line where it is transformed to a lower voltage, converted to direct current, and then by means of feeders is distributed at 600 volts or thereabouts to the third rail.

In 1908 the Midland Railway Company opened for traffic the electrified line connecting Lancaster, Morecambe, and Heysham. The method of electrification was a departure from the general direct current practice hitherto applied to electrified lines in this country. Power was supplied to the trains at 6,600 volts, single phase, at twenty-five alternations per second, along an overhead conductor. The pressure was reduced by transformers carried on the motor-coach itself, and was then used by single-phase motors. The traffic conditions on this line are simple.

In December 1909 the electrified portion of the London, Brighton, and South Coast Railway from Victoria, round by Denmark Hill to London Bridge was opened for traffic. This work marks an epoch in the history of electric traction in England. For the first time the single-phase system was applied to meet the exacting traffic conditions of a London suburban service where the main condition is that the trains should be accelerated rapidly. The system has shown that it can meet all the conditions of the service perfectly. Energy is purchased and is distributed by overhead conductors direct to the trains at 6,600 volts, single phase, at twenty-five alternations per second where it is used by the single-phase motors after suitable transformation by apparatus carried under the motor carriage. The results of this electrification will be of unusual interest, because not only has the method applied shown itself to be quite suitable for dealing with a stopping traffic where quick acceleration is the dominating condition, but it contains the germ of practicable long-distance electrification. The near future may see the extension of the system to the line between London and Brighton, giving a frequent non-stop service which would bring Brighton in point of time nearer than the suburbs on opposite sides of London are to one another.

Some particulars of the electric railways of the country are given in Table V. More details will be found in a table published annually by the *Electrician* entitled 'Tables of Electric Lighting, Power, and Traction Undertakings of the United Kingdom' and in the Railway Returns of the Board of Trade.

Power Signalling.

During the last ten years a considerable number of trial installations of power-signalling apparatus have been made by the railway companies of this country. The electric lines have generally adopted power signalling, and the District Railway has installed a complete system on all its lines and branches.

The term 'power signalling' is applied to any equipment in which the actual movements of the points and signals are done by power, the signalman's work being thus reduced to the movement of small light control levers or switches. Of the several systems tried and proposed three bulk largest in the equipments applied in this country, namely, the all-electric, the low-pressure pneumatic, and the electro-pneumatic systems.

The 'all-electric' system is represented by installations of the McKenzie-Holland and Westinghouse system on the Metropolitan and Great Western Railways, by installations of the 'Crewe' system on the London and North Western Railway, and by installations of Siemens Brothers on the Great Western Railway. The general feature of the all-electric system is that the points are operated by motors sunk in a pit by the side of the rails, the signals are pulled off electrically, and all the apparatus is controlled electrically.

The low-pressure pneumatic system is represented by installations on the London and South Western Railway and the Great Central Railway. The points and signal arms are moved by air compressed to about 20 lb. per square inch, and led to cylinders connected to the points and to the signal-arms. The control is also done by means of compressed air, small pipes leading from each air-cylinder to the cabin.

The electro pneumatic system has found most favour in this country up to the present time. The equipment installed includes such notable stations as the

Central at Newcastle with 494 levers, and the Glasgow Central with 374 levers, and the whole of the Metropolitan District system of underground railways. In this system an air-cylinder is connected to each set of points and to each signal-arm. Air compressed to 65 lb. per square inch is supplied to the cylinders from a main running alongside the railway kept charged by small air-compressors placed at convenient intervals. Each air-cylinder is provided with a small three-way air-valve operated by an electro-magnet. The movement of each air-valve is controlled electrically from the cabin through the electro-magnet associated with it. The system grouped round any one signal-cabin may be regarded as an engine fitted with a large number of cylinders, each working intermittently by compressed air, and where in each the valve-rod has been changed to an electric cable, all the cables being led to a signal-cabin where the operation of the valves is done by means of an apparatus which is as easily played upon as a piano, with this difference, however, that the notes are mechanically interlocked so that a signalman cannot play any tune he pleases, but only a tune which permits of safe traffic movement. Moreover, the instrument is so arranged that the movement of the small lever determining the movement of a signal-arm cannot be completed unless the signal-arm actually responds to the intention of the signalman; thus detecting any fault in the connections between the box and the arm.

The obvious advantage of power signalling is the large reduction of physical labour required from the signalman. His energy can be utilised in thinking about the traffic movements rather than in hauling all day at signal levers. One man at a power frame can do the work of three at the ordinary frame. The claims made for power signalling, in addition to the obvious advantage of the reduction of labour, are briefly that the volume of traffic which can be dealt with is largely increased, that the area of ground required for the installation is considerably less than with the ordinary system, with its rodding, bell-crank levers, chains, and pulleys, and that where the conditions are such that power signalling is justified the maintenance cost is less than with a corresponding system of normal equipment.

Automatic Signalling.

Several of the power-signalling installations are automatic in the sense that between signal-cabins on stretches of line where there are no junctions or crossover roads requiring the movement of points, the movement of the signal-arm protecting a section is determined by the passage of the train itself. The most important equipment of this kind is that installed on the group of railways forming the 'Underground' system. This includes the District Railway with all its branches. On this line the particular system installed is the electro-pneumatic, modified to be automatic except at junctions. Signal-cabins are placed only at junctions and at places where points require to be operated. The stretch of line to be automatically signalled is divided into sections, and the entrance to each section is guarded by a signal-post. Calling two successive sections A and B, the train as it passes from Section A to Section B must automatically put the signal at the entrance to B to danger, and at the same time must pull off the signal at the entrance to A. These operations require the normal position of the signal-arm to be 'off' instead of at danger, as in the usual practice. The position of the arm in this system conveys a direct message to the driver. If 'on' he knows that there is a train in the section; if 'off' he knows that the section is clear. Each signal-arm is operated by an air motor as briefly described above, but the cables from the valves are now led to relays at the beginning and end of the section which the signal protects. The contrivance by means of which the train acts as its own signalman is briefly as follows. One rail of the running track is bonded, and is connected to the positive pole of a battery or generator. The opposite rail is divided into sections, each about 300 yards long, bonded, but insulated at each end from the rails of the adjacent sections and each section is connected to a common negative main through a resistance. A relay is placed at the beginning and at the end of each section, and is connected across from the positive to the negative rail. Current flows and energises the relay, in which condition the relay completes a circuit to the electro-magnet operating the admission-valve of the air-cylinder on the signal-post, air is admitted, and the signal-arm is held off. This is the normal condition at each end of the circuit. When a train enters a section it short-circuits the

relays through the wheels and axles, in consequence of which the relays, de-energised, break the circuit to the admission-valve, which closes, and allows the air in the cylinder to escape, and the signal-arm, moved by gravity alone, assumes the 'on' or danger position. At the same time the short circuit is removed from the section behind, directly the train leaves it, the relays are at once energised, the admission-valve to the air-cylinder on the protecting post of the section is opened, air enters, and the signal is pulled down to the 'off' position.

The speed at which traffic can be operated by this system of power signalling is remarkable. At Earl's Court junction box forty trains an hour can be passed each way—that is eighty per hour—handled by the one signalman in the box. As the train approaches the box both its approach to the section and its destination must be notified to the signalman. When it is remembered that with ordinary signalling, to take an express train for example, a signalman hears some twenty-four beats on the gongs in his box, and sends signals to the front and rear box which give altogether some twenty-four beats on the gongs in these two boxes, forty-eight definite signals in all, for every express train he passes into the section which his signals protect, it will be understood that the system must be profoundly modified to admit such a speed of operation as eighty trains per hour per man. The modification is radical. No gong signals are used at all. There is a small cast-iron box standing opposite the signalman with fifteen small windows in it, each about an inch and a half square. Normally each window frames a white background. A click in the box announces the approach of a train, and a tablet appears in one of the empty windows showing by code the destination of the train. The signalman presses a plug in the box, a click is heard, and a tablet is seen in a precisely similar apparatus in the next box. When the train passes the man presses another plug and the tablet disappears.

Four wires run between the signal-boxes along the railway, and by combining the currents along the four wires in various ways fifteen definite signals can be obtained, a number sufficient for the District traffic. Each of the fifteen combinations is arranged to operate one particular tablet in the box. Current from these four wires is tapped off at intermediate stations and is used to work a train indicator showing the passengers assembled on the platform the destinations of the next three trains. The whole equipment is a triumph of ingenuity and engineering skill, and is a splendid example of the way electricity may be used to improve the railway service quite apart from its main use in connection with the actual driving of the trains.

The facts and problems I have brought before you will, I think, show the important influence that scientific discovery has had upon our railway systems. Scientific discovery and mechanical ingenuity have reduced the cost of locomotive working to a point undreamt of by the pioneer locomotive builders. Electric railways are the direct fruit of the discoveries of Faraday. The safety of the travelling public was enormously increased by the invention of continuous brakes and by the discovery of the electric telegraph, and is greatly increased by the development of modern methods of signalling; and the comfort of travellers is increased by modern methods of train-lighting, train-warming, and the train kitchen. Inventions of a most ingenious character have from time to time been made in order to furnish a steady and ample light in the carriages. The smoothness of travelling on our main lines is evidence of the thought which has been lavished both on the wheel arrangements of the carriages and on the permanent way. Problems in connection with the continuous brake are many and interesting. Some of the problems of modern signalling would have quite baffled the scientific electrician a quarter of a century ago. When engineers endeavour to apply the results of scientific discovery they often find themselves confronted by new problems unperceived by the scientist. Together they may find a solution and thus enlarge the boundaries of knowledge and at the same time confer a practical advantage on the community. The pure scientist, the practical engineer, act and react on one another both to the advantage of pure science and to the advantage of the national welfare. The future success of our railways depends upon the closer application of scientific principle both to the economic and engineering problems involved in their working, some decrease in unprofitable competition with one another, and a more just appreciation on the part of the State of the part railway companies play in our national well-being.

The following Paper was then read :—

The Testing of Lathe Tool Steels.[1]
By Professor W. RIPPER, *D.Eng.*, *M.Inst.C.E.*

A great deal of testing of lathe cutting tools has been done in the past by various experimenters, and is being done every day by steel manufacturers for their own information, but there is, unfortunately, an entire absence of uniformity of standard in the making of these tests. There are two methods of testing most commonly adopted. The first is to find the length of time the tool will run in the lathe under a given set of constant conditions before requiring regrinding; the second is to find the cutting speed which shall cause the edge of the tool to be completely ruined in twenty minutes.

Tests representing prolonged durability are of doubtful value. It is more to the purpose to know the highest cutting speed which may be maintained during some practical period of time—say, twenty or thirty minutes—without regrinding.

Mr. Taylor recommends that in the case of the twenty minutes' test about eight tools of each kind should be prepared—say, $1\frac{1}{8}$ by $1\frac{3}{8}$ and about 18 inches long—treated and shaped in every way alike. They should then be run one tool after another each for a period of twenty minutes, and each at a little faster cutting speed than its predecessor, until the cutting speed has been found which will cause the edge of the tool to be completely ruined at the end of the twenty minutes. This speed is then called the 'standard speed.'

As an improvement on each of the previous methods of testing the writer submitted a new method, which he calls the 'speed-increment test,' and which he has found to give reliable results with a minimum expenditure of time and material.

The method is as follows :—

A testing lathe sufficiently large for the purpose, and driven electrically, is so fitted as to be capable of a very fine adjustment of speed of rotation. The tool to be tested is started on a standard cut—say, $\frac{1}{4}$ by $\frac{1}{32}$—in the testing lathe at a surface speed of, say, 30 feet per minute, and the cutting is allowed to proceed under a gradually increasing rate of speed by equal increments of one foot per minute, each minute throughout the test, until the tool breaks down. That is to say, the speed increment is increased gradually and regularly while the test is proceeding, in the same way as the load increment is increased in the tensile test of a steel bar in the testing machine. Then, if the mean cutting speed in inches from start to finish of the trial be multiplied by the duration of the trial in minutes and by the area of the cut, the result is equal to the number of cubic inches of material turned off by the tool during the test, and this is the measure adopted to represent the merit of the tool.

FRIDAY, SEPTEMBER 2.

The following Report and Paper were read :—

1. *Third Report on Gaseous Explosions.*—See Reports, p. 199.

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2. *The Testing of Files.*[2] *By* Professor W. RIPPER, *D.Eng.*, *M.Inst.C.E.*

The writer is not aware of the existence, until recently, of any method of testing the cutting power of files, except by handing the files to skilled workmen and obtaining their reports upon them. This method is obviously open to grave objections, but a few years ago the Herbert file-testing machine was introduced,

[1] Published in *Engineering*, September 9, 1910.

[2] Published in the Proceedings of the Sheffield Society of Engineers and Metallurgists, November 1910.

and, as a result, files are now required to reach a certain standard of cutting power. A description of this machine with illustrations was given.

Unfortunately very early in the history of the machine doubts were entertained as to the accuracy of the results obtained by it, as files known to be good were condemned by it.

Eventually the writer was asked to report on the Herbert file-testing machine, and a large number of tests were accordingly made. The results of these were in many cases normal, but in others they showed extraordinary differences of effectiveness of cutting power, not only among files said to be in all respects alike, but between the two opposite sides of the same file.

The writer reported that the machine appeared to be defective in one important point—namely, that it treated the file as a machine tool instead of as a hand tool; thus in the machine the file moves across the face of the test bar through an absolutely constant path, the respective teeth of the file each stroke working in identically the same graves or furrows on the face of the test-bar stroke after stroke. The result is that the face of the work occasionally becomes glazed in appearance and the file ceases to cut, though the file itself may not be worn out. In the case of hand-filing no two strokes are made in exactly the same direction. The conditions, therefore, under which the tests are made in the machine differ from those under which the file is worked in actual practice, and this difference works, at least in some cases, to the disadvantage of the file.

For the purpose of removing this objection the writer has devised an addition to the Herbert machine, by means of which the path of the file in the machine is no longer a constant one, but changes its direction stroke by stroke as in the case of hand-filing. To secure this the file is no longer held rigidly at its two ends, but is connected by ball-joints, the effect of which is equivalent to that of a wrist movement at each end of the file. The variation of the path of the file each stroke is obtained by slightly shifting the position of one end of the file, relatively to the other end, by a simple mechanism during each return stroke, so that on the following working stroke it moves in a different path from that which it had in the preceding stroke. The means by which this movement is obtained will be explained and illustrated by diagrams.

The addition of this arrangement to the Herbert file-testing machine has resulted in the removal to a large extent of the irregular results previously obtained from files of similar quality.

MONDAY, SEPTEMBER 5.

The following Papers were read :—

1. *The Electrification of the London, Brighton, and South Coast Railway between Victoria and London Bridge. By* PHILIP DAWSON.

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2. *On the Use of an Accelerometer in the Measurement of Road Resistance and Horse Power.*[1] *By* H. E. WIMPERIS, *M.A., Assoc.M.Inst.C.E.*

The author described the form of accelerometer recently invented by him and constructed by Messrs. Elliott Bros. The instrument consists of a brass box about four inches across containing a copper disc mounted on a vertical pivot and 'damped' in its motions by a permanent magnet. The c.g. of the disc is purposely removed from the axis so that, when the box moves forward, one side of the disc tends to lag behind, thus partially winding up a coiled spring and actuating a pointer which moves over a scale. To render the reading unaffected by any accelerations at right angles to the direction of motion, a second parallel axis is fitted, which is geared to the first one, and has attached to it masses having the same mass moment as the disc itself. Couples about these two axes add up in the direction of motion, but neutralise one another in any direction at right angles.

[1] Published in the *Engineer*, September 16, 1910.

The accelerometer therefore reads in one of the three directions of space only, and is not affected by even violent movements in the other two directions.

With this instrument the author has measured the road resistance of various classes of road and has obtained figures varying from 50 to 210 lb. per ton. On main line railways the resistance is usually from 12 to 30 lb. per ton, depending on the speed. Measurements have also been made of the resistance to motion when a motor car is coasting. In this way the h.p. and the engine friction can be measured and a figure for the mechanical efficiency be obtained.

The conclusions reached may be summed up as follows. By the use of the accelerometer road resistances can be read off at sight; the air resistance of various shapes of car body can be determined; the b.h.p. and i.h.p. of the engine can be obtained for various speeds; and it is possible to trace step by step the losses of power in transmission to the road wheels.

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3. *The Cyclical Changes of Temperature in a Gas-engine Cylinder near the Walls.* By Professor E. G. Coker, *M.A., D.Sc.*

Experiments described in *Engineering* for October 1908 show that the temperature at the inner surface of a small gas-engine is about 240° C., and the cyclical variation is usually less than 10° C.

The steady conditions of low temperature at the wall-surface are maintained by the jacket-water, although the explosion of the gaseous mixture produces very great changes of temperature close to the walls.

This variation has not hitherto been measured for a complete cycle owing to the difficulties which occur in measuring the highest temperature of the explosion. In order to obtain the cyclical variation near the walls, a couple was made of an alloy of 10 per cent. iridium and platinum, with a pure platinum wire, and this was secured in a metal plug so that it projected ¼ inch into the cylinder. On light loads and weak mixtures the cycle remained unbroken, but near full load the platinum wire melted.

Couples made from 10-per-cent. alloys of iridium and rhodium with platinum were afterwards used, having an electromotive force E above 500° C. given by $E = -174 + 7{\cdot}6075\,T - 0{\cdot}00167\,T^2$, where T is the temperature centigrade. The junctions were rolled down to five or six ten-thousandths of an inch thickness and inserted at a depth of ½ inch from the cylinder-wall.

These couples were able to withstand the highest temperatures near the walls, and they were not melted except during abnormal explosions.

Measurements of the cyclical variations showed a variation of E.M.F. lying between 1·56 and 7·83 milli-volts with an average cold junction temperature of 30° C. The temperature variation corresponding to these values ranges between 250° C. and 1700° C.

In estimating the highest temperature reached, the upper limit of temperature is indicated by the partial melting of one of the wires when the engine ran above its full normal load, and the lower limit is indicated by the melting of platinum wire. The melting-point of platinum is 1710 ± 5° C., and, in the absence of definite values of the melting-points of the alloys used, it is assumed that both are below the melting-point of iridium, for which Violle's value is 1950° C. The probable causes of error in the measurements are discussed, and the conclusion is reached that the temperature at the place of measurement has a maximum value between 1850° and 1900° C.

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4. *The Value of Anchored Tests of Aerial Propellers.*[1] By W. A. Scoble.

Joint Discussion with Section A on the Principles of Mechanical Flight. Opened by Professor G. H. Bryan, *F.R.S.*

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[1] Published in *Engineering*, September 9, 1910.

TUESDAY, SEPTEMBER 6.

The following Papers were read :—

1. *The Optical Determination of Stress.*[1] *By* Professor E. G. Coker, *M.A.*, *D.Sc.*

The experimental determination of the state of stress in a body by purely mechanical means and apparatus has the disadvantage that it is necessary for accuracy of measurement that a definite length, area, or volume be maintained in a standard condition, and the stress at a point cannot therefore be accurately determined if the stress is a rapidly varying one.

The property possessed by glass of becoming doubly refractive under stress has been frequently utilised to determine the state of plane stress at a point in it by the colour fringes produced, but the difficulty of forming any but the simplest objects in glass has prevented its extensive use for experimental work.

Other substances have been tried, and a preparation of nitro-cellulose in commercial use has been found which answers exceedingly well for experimental work. Its properties are very different from glass, and experiments show that the modulus for tension is approximately 300,000 in pounds and inches and the value of 'Poisson's' ratio 0·37, plate-glass having the corresponding values of $10{\cdot}5 \times 10^6$ and 0·227 respectively. For determining stresses a method of matching colours is adopted, in which a uniformly stressed test-bar is loaded until the colour produced by the retardation of a plane or circularly polarised ray corresponds to that produced at a point in the object under stress. The relative retardations R of the ordinary and extraordinary rays is assumed to be similar to glass and to follow the law expressed by $R = C (X - Y) T$, where X, Y are the principal stresses at a point, T is the thickness of the material and C is an optical constant.

The stresses at the cross-section of an eccentrically loaded tie-bar and at the principal section of a hook are shown to be in fair agreement with theory.

To determine the lines of principal stress in a body the loci of points at which the directions of the principal stresses are the same are found by using plane polarised light, and from the curves so found the directions of the principal stresses are determined.

From the curves of principal stress, coupled with a knowledge of the position of the isochromatic lines, the stresses at any point may be determined by the use of Maxwell's method.

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2. *On the Direct Measurement of the Rate of Air or Gas Supply to a Gas-Engine by means of an Orifice and* U-*Tube.*[2] *By* Professor W. E. Dalby, *M.A.*, *M.Inst.C.E.*

An orifice in conjunction with an anemometer was used to measure the air-supply at the Ashton trials of the Committee of the Institution of Civil Engineers, and more recently Professor Ashcroft contributed a paper to the Institution of Civil Engineers describing a method of using an orifice in conjunction with a specially designed indicator to measure the difference of pressure on the two sides of the orifice. In the Ashton trials the air-supply is inferred from the anemometer readings, and in Professor Ashcroft's method the air-supply is inferred from the difference of pressure in conjunction with the orifice, which was made about the same size as the suction-pipe of the engine, in consequence of which the difference of pressure was very small. In each case calibration was effected by driving the engine from the crank-shaft end, and then from indicator diagrams deducing the weight of air passing through the orifice. This deduction cannot be made accurately unless the temperature can be accurately measured at one point on the indicator diagram. In neither case could this temperature be measured. The gas-engine used by the author is fitted with apparatus by means of which the temperature corresponding to the pressure and volume

[1] Published in the *Phil. Mag.*, October 1910.

[2] Published in *Engineering*, September 9, 1910.

at an assigned crank-angle can be accurately measured with a platinum thermometer. Thus all the data are observed from which the weight of air drawn through the orifice per cycle can be computed. Indicator diagrams were taken with an optical indicator giving accurate results. Every indicator-card was calibrated for pressure *in situ*. The peculiarity of the method is that a relatively small orifice is used—so small, in fact, that the difference of pressure on the two sides of it is equivalent to about one foot of water under normal conditions of running. This difference of pressure can then be measured by means of a U-tube, and small variations of head are easily observed. Numerous experiments established the fact that the coefficients of the orifices tried were practically constant and equal to 0·6. The gas-supply can be measured through an orifice in the same way. Hence the mixture of air and gas passing into the cylinder can be obtained from two readings, with suitable corrections for density, at any time during the run. The orifices, in combination with their U-tubes, become rate measurers, the one giving the rate at which air is supplied to the engine, and the other the rate at which gas is supplied.

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3. *The Laws of Electro-Mechanics.*[1] *By* Professor S. P. Thompson, *F.R.S.*

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4. *The Testing of Heat-insulating Materials.*[2] *By* Frederick Bacon.

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5. *A New Method of producing High-tension Electrical Discharges.*[3] *By* Professor E. Wilson *and* W. H. Wilson.

According to this method energy is taken from an alternating or continuous current source and stored in a magnetic field by an inductance; it is then permitted to surge into a condenser, which forms with the inductance a *low* frequency oscillatory circuit. When the energy is accumulated in the condenser the latter is mechanically bridged across the primary winding of an induction coil, with which it forms a *high* frequency oscillatory circuit. The energy is then transmitted by the secondary winding of the induction coil to the work circuit, and can be of an oscillatory or uni-directional character according to the purpose in view. The apparatus is light, efficient, and cheap, and is especially suitable for radio-telegraphy, *x*-ray, ignition, and other work in which high tension electricity is employed.

WEDNESDAY, SEPTEMBER 7.

The following Papers were read :—

1. *Gravity Self-raising Rollers.*[4] *By* R. W. Weekes.

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2. *The Mechanical Hysteresis of Rubber.*[5] *By* Professor Alfred Schwartz.

The increasing importance of the applications of rubber in the Arts calls for carefully standardised tests of the properties of this material.

The physical properties of rubber of which use is made in industrial work are its elasticity, compressibility, extensibility, tenacity, flexibility, adhesiveness,

[1] Published in abstract in *Engineering*, September 16, 1910.
[2] Published in *Engineering*, September 16, 1910.
[3] Published in the *Electrician*, September 9, 1910.
[4] Published in *Engineering*, October 14, 1910.
[5] Published in the *Electrical Review*, September 23, 1910, and in *Engineering*, September 16, 1910.

resistance to certain chemical agents, impermeability to water, solubility in certain liquids, and electrical resistance and dielectric strength.

The methods of testing employed at the present time consist in chemical analysis and in the determination of the elongation and load at rupture and of the sub-permanent set resulting from a given extension maintained for a given time.

It is evident that the chemical tests can give no indication with regard to many of the physical properties enumerated above, and it would seem that their true function lies in the determination of *causes*, while the mechanical tests should deal with the *effects* produced by these causes in the commercial product.

The mechanical tests should then form the primary tests of both the manufacturer and the purchaser, and should, when necessary, be supplemented by the chemical tests, either as confirmatory tests or for the elucidation of the causes of the defects indicated by the mechanical tests. In the case of raw rubbers the chemical tests give little or no indication of the value of the product for industrial purposes, and it is suggested that test pieces for such materials should be prepared from the so-called 'Admiralty mixing,' consisting of 60 per cent. rubber, 3 per cent. sulphur, and 37 per cent. zinc oxide, and be subjected to the hysteresis tests hereinafter described.

The author has designed a machine in which a specimen of rubber of standard dimensions is loaded at a given rate to a given percentage of its breaking load. The load is then removed at the same rate, and a graphical record is obtained on the chart table of the machine of the extension and retraction curves.

Rubber possesses very considerable mechanical hysteresis, and a consideration of the loop diagram obtained from the machine enables the following physical quantities to be determined for any given test piece :—

(1) The rate of extension with load.
(2) The work done in extension.
(3) The work done by the rubber in retracting.
(4) The work expended in the rubber itself.
(5) The sub-permanent set remaining after a given extension.

The limits of the hysteresis loop may also be set in terms of extension in place of load as already stated. The author finds that for a given rubber the following laws hold good :—

(*a*) The load per unit area of the initial cross-sectional area of the test piece is constant for a given extension of the test piece and independent of the cross-sectional area of the specimen within certain limits.

(*b*) The work done in extension, in retraction, and in the rubber itself is within certain limits proportional to the cross-sectional area of the test piece, and is directly proportional to the length of the specimen with a given percentage extension.

On the completion of the first cycle of extension and retraction the specimen may be subjected to a series of similar cycles the limits of which may be set either by a given maximum extension or a given maximum load.

For high-grade rubbers the areas of the loops for successive cycles become constant after about the sixth loop, when the subsequent cycle loops are taken up to the same maximum load as that for the first loop.

The author finds that the extension for a given load limit increases with each successive cycle, and that the rate of increase follows a logarithmic law from the second cycle onwards.

Applications of the hysteresis test are given to the determination of various grades of rubber, of the quantity of rubber in a given mixing, of the degree of vulcanisation, and of the deterioration due to age or high temperature.

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3. *The Utilisation of Solar Radiation, Wind Power, and other Natural Sources of Energy. By* Professor FESSENDEN.

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4. *Experimental Investigation of the Strength of Thick Cylinders. By* G. COOK.

SECTION H.—ANTHROPOLOGY.

PRESIDENT OF THE SECTION.—W. CROOKE, B.A.

THURSDAY, SEPTEMBER 1.

The President delivered the following Address :—

ONE-AND-THIRTY years have passed since the British Association visited this city. At that time anthropology was in the stage of probation and was represented by a branch of the section devoted to biology. Since then its progress in popularity and influence has been continuous, and its claims to be regarded as a science, with aims and capabilities in no way inferior to those of longer growth, are now generally admitted. Its advance in this country is largely due to the distinguished occupant of this chair at our last meeting in Sheffield, Dr. E. B. Tylor, who during the present year has resigned the professorship of anthropology in the University of Oxford. Before this audience it is unnecessary for me to describe in detail the services which this eminent scholar and thinker has rendered to science. His professorial work at Oxford; his unfailing support of the Royal Anthropological Institute and of this section of the British Association; his sympathetic encouragement of a younger generation of workers—these are familiar to all of us. Many of those now engaged in anthropological work at home and abroad date that interest in the study of man, his culture and beliefs, which has given a new pleasure to their lives, from the time when they first became acquainted with his "Primitive Culture' and 'Researches into the History of Mankind.' These words enjoy the almost unique distinction that, in spite of the constant accumulation of new material to illustrate an advancing science, they still maintain their authority; and this because they are based on a thorough investigation of all the available material and a profound insight into the psychology of man at the earlier stages of culture. He has laid down once for all the broad principles which must always guide the anthropologist: that a familiarity with the principles of the religions of the lower races is as indispensable to the scientific student of theology as a knowledge of the lower forms of life, the structure of mere invertebrate creatures, is to the physiologist. 'Few,' he assures us, 'who will give their minds to master the general principles of savage religion will ever think it ridiculous or the knowledge of it superfluous to the rest of mankind. . . . Nowhere are broad views of historical development more needed than in the study of religion. . . . Scepticism and criticism are the very conditions for the attainment of reasonable belief.' I need hardly say that his exposition of the principles of animism, as derived from the subconscious mental phenomena of dreams and waking visions, has given a new impulse and direction to the study of the religion of savage races.

Dr. Tylor, on his retirement from the active work of teaching, carries with him the respectful congratulations and good wishes of the anthropologists here assembled, all of whom join in the hope that the Emeritus Professor may be able to devote some of his well-earned leisure to increasing the series of valuable works for which we are already indebted to him.

In his address from this chair Dr. Tylor remarked that twenty years before that time it was no difficult task to master the available material. 'But now,' he

added, 'even the yearly list of new anthropological literature is enough to form a pamphlet, and each capital of Europe has its anthropological society in full work. So far from any finality in anthropological investigation, each new line of argument but opens the way to others behind, while those lines tend as plainly as in the sciences of stricter weight and measure toward the meeting ground of all sciences in the unity of Nature.'

Since these words were written there has been a never-ceasing supply of fresh literature, which is well represented in the publications of the present year. Every contributor to this science must now be a specialist, because he can with advantage occupy only one tiny corner of the field of humanity; and even then he is never free from a feeling of anxiety lest his humble contribution may have been anticipated by some indefatigable foreign scholar. In short, the attempt to give a general exposition of the sciences devoted to the study of mankind has been replaced by the monograph. Of such studies designed to co-ordinate and interpret the facts collected by workers in the field we welcome two contributions of special importance.

Professor J. G. Frazer has given us a monumental treatise on totemism and exogamy, in which, relying largely on new Australian evidence and that collected from Melanesia by Dr. Haddon and his colleagues, Dr. Rivers and Dr. Seligmann, he endeavours to prove that totemism originated in a primitive explanation of the mysteries of conception and childbirth. As contributing causes he discusses the influence of dreams and the theory of the external soul, the latter being occasionally found connected with totemism; and he points out that one function of a totem clan was to provide by methods of mimetic or sympathetic magic a supply of the totem plant or animal on which the existence of the community depends, this function being not metaphysical or based on philanthropic impulse, but on a cool but erroneous calculation of economic interest. He has also cleared the ground by dissociating totemism from exogamy, the latter, as an institution of social life, being, he believes, later in order of time than totemism, and having in some cases accidentally modified the totemic system while in others it has left that system entirely unaffected. The law of exogamy is, in his opinion, based mainly on a desire to prevent the union of near relations, and on the resulting belief in the sterilising effects of incest upon women in general and edible animals and plants. In dealing with totemism as a factor in the evolution of religion he gives us a much-needed warning that it does not necessarily develop, first into the worship of sacred animals and plants, and afterwards into the cult of anthropomorphic deities with sacred plants and animals for their attributes. In the stage of pure totemism totems are in no sense deities, that is to say, they are not propitiated by prayer and sacrifice; and it is only in Polynesia and Melanesia that there are any indications of a stage of religion evolved from totemism, a conclusion which demolishes much ingenious speculation. It is hardly to be expected that in a field covered by the wrecks of many controversies these views will meet with universal acceptance. But the candour with which he discards many of his own theories, and the infinite labour and learning devoted to the preparation of his elaborate digest, deserve our hearty recognition.

In his treatise on 'Primitive Paternity,' Mr. E. S. Hartland deals with the problems connected with the relations of the sexes in archaic society. Mother-right he finds to be due not so much to the difficulty of identifying the father as to ignorance of physiological facts; and he supposes that the transition from mother-right to father-right originated not from a recognition of the physical conditions of paternity, but from considerations connected wth the devolution of property; as Professor Frazer states the case, it arises from a general increase in material prosperity leading to the growth of private wealth.

We also record the steady progress of the great 'Encyclopædia of Religion and Ethics,' under the editorship of Dr. J. Hastings, which promises to provide an admirable digest of the results of recent advances in the fields of comparative religion and ethnology.

It is now admitted by all students of classical literature that the material collected from the lower races is an indispensable aid to the interpretation of the myths, beliefs, and culture of the Greeks and Romans. Most of our universities provide instruction of this kind; and Oxford has opened its doors to a special

course of lectures dealing with the relation of anthropology to the classics. One of its most learned mythologists, Dr. L. R. Farnell, when about halfway through his treatise on the cults of the Greek states, admitted the increasing value of the science in elucidating the problems on which he was engaged. Even with this well-advised change of method he has left the field of peasant religion, nature-worship, and magic, which must form the starting-points for the next examination of Greek beliefs, practically unworked. The formation of a Roman Society, working in co-operation with and following the methods which have been adopted by the Society for the Promotion of Hellenic Studies, is a fresh indication of the increasing importance of the work upon which we are engaged.

In the field of archæology Dr. A. J. Evans has commenced the publication of the Minoan records, which open up a new chapter in the early history of the Mediterranean. It is now certain that the origin of our alphabet is not to be found, as De Rougé supposed, in the hieratic script of Egypt, but in the Cretan hieroglyphs; and that the influence of the Phœnicians in its development was less important than has been generally supposed. Before the full harvest of these excavations can be reaped we may have to await the discovery of some bilingual document, like the Rosetta Stone, which will solve the mysteries of the Minoan syllabary.

As regards physical anthropology, the validity of the use of the cephalic index, particularly in discriminating the elements of mixed populations, has been questioned. The recent Hunterian lectures delivered by Professor A. Keith, as yet published only in the form of a summary, are designed to place these investigations on a more scientific basis. In particular increased attention is being given to the influence of environment in modifying a structure generally so stable as the human skull. Thus it has been ascertained that the immigrant into our towns, by some process of selection or otherwise, develops a longer and narrower head than the countryman. The recent American Commission, under the presidency of Professor Boas, reports that 'racial and physical characteristics do not survive under the new climate and social environment. . . . Children born even a few years after the arrival of their parents show essential differences as compared with their European parentage. . . . Every part of the body is influenced, even the shape of the skull, which has always been considered to be the most permanent hereditary characteristic.' Similar results appear from a comparison of the American negro with his African ancestor.

I may refer briefly to the work on folk-lore. Though in recent years it has not maintained the importance which it at one time secured in the proceedings of this section, we still regard it as an essential branch of the study of man. The Folk-Lore Society, after thirty-two years' useful work, finds that much still remains to be done in these islands to secure a complete record of popular beliefs and traditions, many of which are rapidly disappearing. It has therefore formulated a scheme for more systematic investigation in those districts which have hitherto been neglected. A committee including representatives of the two allied sciences is also engaged on the necessary task of revising and defining the terminology of anthropology and folk-lore.

The materials collected by field workers in various regions of the world, and popular accounts of savage religion, customs, and folk-lore continue to arrive in such increasing numbers that the need of a central bureau for the classification of this mass of facts has become increasingly apparent. It is true that we have suffered a set-back, it is to be hoped only temporary, in the rejection of an appeal made to the Prime Minister for a grant-in-aid of the Royal Anthropological Institute. But if we persist in urging our claims to official support the establishment of an Imperial Bureau of Ethnology cannot be long deferred.

One result of this accession of fresh knowledge, largely due to improved methods of research, is to modify some of our conceptions of savage psychology. We now understand that side by side with physical uniformity there may be wide differences arising from varieties of race and environment. It is becoming generally recognised that we can no longer evade the difficulty of interpreting beliefs and usages by referring them to that elusive personality, primitive man. Between the embryonic stage of humanity and the present lie vast periods of time; and no methods of investigation open to us at present offer the hope of

successfully bridging this gap in the historical record. To use the words of Professor Frazer: 'It is only in a relative sense, by comparison with civilised men, that we may legitimately describe any living race of savages as primitive.' Hence the hypothesis of the unilinear evolution of culture which satisfied an earlier school will no longer bear examination.

Further, not to speak of the artistic endowments of palæolithic man, we find to our surprise that a race like the Australian Arunta, whose lowness in the scale of humanity does not necessarily connote degradation, has worked out with exceptional ability through its tribal council their complex and cumbrous systems of group marriage and totemism. They have developed a cosmogony which postulates the self-existence of the universe; they have reached a belief in reincarnation and transmigration of the soul. So far from their social system being rigid it is readily modified to suit new conditions. They live in peace with neighbouring tribes, and have established the elements of international law. On the moral side, though there is much that is cruel and abhorrent, they are not wanting in kindliness, generosity, gratitude. The savage, in short, is not such an unobservant simpleton as some are inclined to suppose; and any interpretation of his beliefs and usages which ignores this fact is certain to be misleading.

This popularisation of our science has not, however, been universally welcomed. It has been urged with much reason that this overabundance of material tends to encourage an unscientific method, particularly the comparison of isolated facts without due regard to the context of culture to which they are organically related. There is much force in this contention; and probably when the work of this generation comes to be critically reviewed we shall be rightly charged with rashly attempting a synthesis of facts not generically related, with reposing too much confidence in evidence collected in a haphazard fashion, and with losing sight of their historical relations in our quest after survivals. Those who have practical experience of work among savage or semi-savage races understand the difficulty of collecting information on subjects outside the range of their material interests. Only a skilled linguist is able to interpret their hazy religious beliefs. We fail to evolve order from what is and always must be chaotic; we fail to discriminate religion from sociology because both are from the savage point of view identical; and generally it is only the by-products of religion, such as demonology, witchcraft, mythology which reward our search. The most dogmatic among us, when they consider the divergent views of Messrs. Spencer and Gillen and Strehlow, may well hesitate to frame theories about the Arunta.

In the next place it has been objected that the scientific side of anthropology is in danger of being submerged by a flood of amateurism. It is only within recent years that a supply of observers trained in scientific methods has become available. Much of the work in India, the Dominions, and other parts of the Empire has been done by amateurs, that is to say, by officers in the service of the Crown, missionaries, or planters, who understand the languages, manners, and prejudices of the people, but have not received the advantage of scientific training. Some of this work is, in its kind, useful; but there seems reason to believe that inquiries conducted by this agency have almost reached their limit. The existing material may be supplemented and corrected by workers of the same class; but from them no important additions to our knowledge can reasonably be expected.

Criticisms such as these have naturally suggested proposals for improving the qualifications of this agency by providing a course of training for public servants before they join their appointments; and excellent arrangements with this object have been made by several of our universities. In addition to this schemes are in the air for the establishment of a School of Oriental Studies in London or of a College for Civilians in Calcutta. We must, however, recollect that the college established by Lord Wellesley at the beginning of the last century with the intention, to use his own words, of promoting among junior officers 'an intimate acquaintance with the history, language, customs, and manners of the people of India,' failed to meet the aims of its founder. We must also remember that recruits for the Colonial services do not undergo any training in this country; and that in the case of the Covenanted Civil Service of India the period extends only to a single year, during which the candidate is expected to learn the rudiments of at least one Oriental language and to acquire some

knowledge of the law and history of India. It seems obvious that this leaves little time for the scientific study of anthropology; and the most that can be expected is to excite in the young official a desire to study the native races and to define the subjects to which his attention may usefully be directed. There is, again, the obvious risk of letting loose the half-trained amateur among savage or semi-savage peoples. He may see a totem in every hedge or expect to meet a corn-spirit on every threshing-floor. He may usurp the functions of the arm-chair anthropologist by adding to his own proper business, which is the collection of facts, an attempt to explain their scientific relations. As a matter of fact, the true anthropologist is born, not made; and no possible course of study can be useful except in the case of the few who possess a natural taste for this kind of work.

Having then practically exhausted our present agency it is incumbent upon us to press upon the Governments throughout the Empire the necessity of entrusting the supervision of ethnographical surveys to specialists. This principle has been recognised in the case of botany, geology, and archæology, and it is high time that it was extended to anthropology. It is the possession of such a trained staff that has enabled the American Government to carry out with success a survey of the natives of the Philippine Islands; and it is gratifying to record that the Canadian legislature, in response to resolutions adopted by this section at the Winnipeg meeting, has recently voted funds to provide the salary of a superintendent of the ethnological survey. We may confidently expect that other governments throughout the Empire will soon follow this laudable example. These governments will, of course, continue to collect at each periodical census those statistics and facts of sociology and economics which are required for purposes of administration. But beyond these practical objects there are questions which can be adequately investigated only by specialists.

The duties of such a director will necessarily be threefold: First, to sift, arrange, and co-ordinate the facts already collected by non-scientific observers; secondly, to initiate and control special investigations, in particular that intensive study of smaller groups within a limited area which, in the case of the survey of the Todas by Dr. Rivers, has so largely contributed to our knowledge of that tribe. Such methods not only open out new scientific fields, but—and this is perhaps more important—establish a standard of efficiency which improves later surveys of these or neighbouring races.

The field for inquiry throughout the Empire is so vast that there is ample room for expeditions independent of official patronage. In some respects the private traveller possesses advantages over the official—in his freedom from the bondage of red tape and from the suspicion which inevitably attaches to the servant of government that his inquiries are conducted with the object of imposing taxation or of introducing some irksome measures of administration. He is always sure to receive the aid of local officers, whose familiarity with the native races must be of the highest value.

The third duty of the director will be to organise in a systematic way the collection of specimens for home and colonial museums. Our ethnographical museums, as a whole, have not reached that standard of efficiency which the importance of the Empire and the needs of training in anthropology obviously require; and our students have to seek in museums at Berlin and other foreign cities for collections illustrative of tribes which have long been subject to British law. It is only necessary to refer to the recent handbook of the ethnographical collections in the British Museum to see that there are wide gaps in the series which might easily be filled by systematic effort. No time is to be lost, because the tragedy of the extinction of the savage is approaching the final act, and our grandchildren will search for him in vain except perhaps in the slums of our greater cities.

Assuming then that in the near future anthropological inquiries will be organised on practical lines, I invite your attention to some special problems in India which deserve intensive study, and which can be solved in no other way. India is a most promising field for such inquiries. Here the student of comparative religion can trace with more precision than is possible in any other part of the Empire the development of animism and the interaction on it of the forces represented by Buddhism, Hinduism, Islam, and Christianity. The anthropologist can observe the most varied types of moral and material culture, from

those represented by the heirs of its historic civilisation down to forest and depressed tribes little raised above the level of savagery.

The first question which awaits examination is that of the prehistoric races and their relation to the present population. Unfortunately the materials for this inquiry are still imperfect. The operations of the Archæological Survey, with the scanty means at its disposal, have rightly been concentrated upon the remains of architecture in stone, which starts from the Buddhist period, and upon the conservation of the splendid buildings which are our inheritance from older ruling powers. The prehistoric materials have been collected by casual workers who were not always careful to record the localities and circumstances of the discovery of their contribution to the local museums. Many links are still wanting, some altogether absent from Indian soil; others which systematic search will doubtless supply. We can realise what the position of prehistoric archæology in Europe would be if the series of barrows, the bone carvings of the cave-dwellers, the relics from kitchen-middens and lake dwellings were absent. The caves of central India, it is true, have supplied stone implements and some rude rock paintings. But the secrets of successive hordes of invaders from the north, their forts and dwellings, lie deep in the alluvium, or are still covered by shapeless mounds. Tropical heat and torrential rain, the ravages of treasure-hunters, the practice of cremation have destroyed much of the remains of the dead. The epigraphical evidence is enormously later in date than that from Babylon, Assyria, or Egypt; and the Oriental indifference to the past and the growth of a sacred literature written to subserve the interests of a priestly class weaken the value of the historical record.

Further, India possesses as yet no seriation of ceramic types such as that devised by Professor Flinders Petrie which has enabled him to arrange the Egyptian tombs on scientific principles, or that which Professor Oscar Montelius has established for the remains of the Bronze Age. Mr. Marshall, the Director of the Archæological Survey, admits that the Indian museums contain few specimens of metal work the age of which is even approximately known.

Though the record of the prehistoric culture is imperfect, we can roughly define its successive stages.

The palæolithic implements have been studied by Mr. A. C. Logan, whose work is useful if only to show the complexity of the problem. Those found in the laterite deposits belong to the later Pleistocene period, and display a technique similar to that of the river-drift series from western Europe. The Eoliths, which have excited such acute controversy, have up to the present not been discovered; and so far as is at present known the palæolithic series from India appears to be of later date than the European. Palæolithic man seems to have occupied the eastern coast of the peninsula, whence he migrated inland, using in turn quartzose, chert, quartzite, limestone, or sandstone for his weapons; that is to say, he seems not to have inhabited those districts which at a later time were seats of neolithic culture. Early man, according to what is perhaps the most reasonable theory, was first specialised in Malaysia, and his northward route is marked by discoveries at Johore and other sites in that region. Thence he possibly passed into India. The other view represents palæolithic man as an immigrant from Europe. At any rate, his occupation of parts of southern India was antecedent to the action of those forces which produced its present form ere the great rivers had excavated their present channels, and prior to the deposition of the masses of alluvium and gravel which cover the implements which are the only evidence of his existence.

Between the palæolithic and the neolithic races there is a great geological and cultural gap; and no attempt to bridge it has been made except by the suggestion that the missing links may be found in the cave deposits when they undergo examination.

There is reason, however, to believe that the neolithic and the Iron Age cultures were continuous, and that an important element in the present population survives from the neolithic period. Relics of the neolithic are much more widely spread than those of the palæolithic age. They extend all over southern India, the Deccan, and the central or Vindhyan range. Up to the present they are scanty in the Punjab and Bengal; but this may be due to failure to discover or identify them. Mr. Bruce Foote has discovered at various sites in

the south factories of neolithic implements associated with wheel-made pottery of a fairly advanced type, showing that the Stone Age has survived side by side with that of metal down to comparatively recent times. The Veddas of Ceylon, the Andamanese, and various tribes on the north-east frontier, in central and southern India, are, or were up to quite recent times, in the Age of Stone. In fact, when we speak of ages of stone or metal we must not regard them as representing division of time but generally continuous phases of culture.

There is no trustworthy evidence for the existence of an Age of Bronze. The single fine implement of this metal which has been discovered is probably, like the artistic vessels from the Nilgiri interments, of foreign origin; and other implements of a less defined type seem to be the result of imperfect metallurgy. This is not the place to discuss the problem of the origin and diffusion of bronze. Babylon, Asia Minor, and China have each been supposed to be a centre of distribution. The Egyptian specimen attributed to the third dynasty, say before the fourth millennium B.C., is believed by Professor Petrie to be the result of a chance alloy; but the metal certainly appears in Egypt about 1600 B.C., and it is believed to have originated in central Europe, where the Zinnwald of Saxony or the Bohemian mines provided a supply of tin. The absence of a Bronze Age in India has been explained by the scarcity of tin and the impossibility of procuring it from its chief source in the Malay-Burman region, where the mines do not seem to have been worked in ancient times. But another view deserves consideration. Professor Ridgeway has shown that all the sites where native iron is smelted are those where carboniferous strata and ironstone have been heated by eruptions of basalt; and iron was thus produced by a natural reduction of the ore. In Africa as well as India the absence of the Bronze Age seems to be due to the abundant supplies of iron ores which could be worked by processes simpler than those required in the case of bronze. In India iron may have been independently discovered towards the close of the neolithic period, and iron may have displaced copper without the intervention of bronze.

However this may be, the Copper Age in India, which has been carefully studied by Mr. V. A. Smith, is of great importance. Implements of this metal in the form of flat and bar celts, swords, daggers, harpoon, spear, and arrow heads, with ornaments and a strange figure, probably human, have been found at numerous sites in northern India. In western Europe, according to Dr. Munro, the Copper Age was of short duration; but Mr. Smith believes that in India the variety of types indicates a long period of development.

No mention of iron occurs in the Rig-Veda; but it appears in the Atharvan, which cannot be dated much later than 1000 B.C. It is now recognised that there is a still obscure stratum of Babylonian influence underlying the Aryan culture; and if, as is generally supposed, the manufacture of iron was established by the Chalybes at the head-waters of the Euphrates, who passed it down the delta, its use may have spread thence among the Indo-Aryans. It certainly appears late in the south Indian dolmen period; and we have the alternatives of believing that it was introduced there by the Dravidian trade with the Persian Gulf, which certainly arose before the seventh century before Christ, or that it was independently discovered by the Dravidians, who still extract it in a rude way from the native ores.

The great series of dolmens, circles, and kistvaens which cover the hills and plateaux of the Deccan and the region to the south seem to belong to the Iron Age. Whether the construction of these monuments was due to the migration of the dolmen-building race from northern Africa, or whether the builders were a local people utilising the material on the spot must remain uncertain. The excavations conducted by Mr. Breeks and others disclose tall jars, many-storeyed cylinders of varying diameter, with round or conical bases, fashioned to rest on pottery ring-stands, like the classical amphorae, or to be imbedded in softer soil. The lids of these vessels are ornamented with rude, grotesque figures of men, animals, or more rarely inanimate objects, depicting the arms, dress, ornaments, and domesticated fauna of the period. It has been suspected that these figurines may be of a date earlier than the implements of iron with which they are associated, and that they were deposited with the dead in a spirit of religious conservatism. At any rate, the costumes and arms represented on the older pottery present no resemblance to those depicted on the later series of dolmens

and kistvaens. The pottery also seems to belong to different periods, the larger jars being of a later date than the true funereal urns which are found at a lower level, and contain a few cremated bones, gold ornaments, bronze and iron rings, with beads of glass or agate. These people clearly regarded bronze as an article of luxury, as it appears in the form of ornaments or in the series of splendid vases preserved in the Madras Museum. It is difficult to suppose that these were of local origin; more probably they were imported in the course of trade along the western coast or from more distant regions.

Another and equally remarkable phase of culture, combining distinctly savage features with a fairly advanced civilisation, is illustrated by the Adittanalur cemetery in the Tinnevelli district recently excavated by Mr. Rea. Two skulls discovered here are prognathous, suggesting a mixture of the Negrito and Dravidian types. There is no trace of cremation, and in most cases the smallness of the urn openings implies that the corpses were exposed to birds of prey, and that only such bones as could be discovered after removal of the flesh were collected for interment; or, according to another interpretation of the facts, we have an instance of the custom of mourners carrying with them, like the modern Andamanese, the relics of the dead. These interments certainly extended over a long period, neolithic weapons being found in some graves, while in others iron arms were discovered fixed point downwards near the urns, as if they had been thrust into the ground by the mourners. In the richer graves gold frontlets, like those of Mycenæ and other Greek interments, were fastened over the forehead of the corpse. These were, like the Greek specimens, of such a flimsy type that they could never have been used in real life. It is a remarkable instance of a survival in custom that at the present day some tribes in this region tie a triangular strip of gold on the forehead of the dead, the import of which, on the analogy of the death masks of Siam, Cambodia, ancient Mexico, and Alaska, we may interpret as an attempt to guard the corpse from the glances of evil spirits while the spirit is on its way to deathland, or to be used in processions of the corpse.

The question remains: To what races may we attribute these successive phases of culture in southern India? The Tamil literature, as interpreted by Bishop Caldwell and Mr. V. Kanakasabhai, shows the existence of an advanced type of archaic culture in this region; but the evidence to connect this with the existing remains is as yet wanting. We may reasonably assume that neolithic man survives in the existing population, because we have no evidence of subsequent extensive migrations, except the much later arrival of Indo-Aryan colonies from the north, and that of the Todas, whom Dr. Rivers satisfactorily identifies with the Nayars and Nambutiri Brahmans of Malabar. The occurrence of a short-headed strain among some tribes in western India probably represents some prehistoric migration by sea or along the coast line from the direction of Baluchistan or the Persian Gulf. The suggestion that it is the result of a Scythian or Hun retreat from northern India in the face of an advancing Aryan movement is not corroborated by any historical evidence, and is in itself improbable. The customs of dolmen and kistvaen burial still persist among some of the present tribes, and they display some reverence for the burial-places of their forgotten predecessors. This feeling may, however, be due to the habitual tendency of the Hindu to perform rites of propitiation at places supposed to be the haunts of spirits, and need not necessarily connote racial identity.

The most primitive type identifiable in the population of south India is the Negrito, which appears among the Veddas of Ceylon, and among the Andamanese, who retain the Negrito skin colour and hair, but have acquired, probably from some Mongoloid stock, distinct facial characters. It has been the habit with some writers to exaggerate the Negrito strain in the south. But tribes like the Badagas and Kotas, which have been classed as representative of this type, possess none of the Negrito characters, which appear only among the more primitive Kurumbas, Malayans, Paniyans, and Irulas. In all the modern tribes the distinctive Negrito marks—woolliness of hair, prognathism, lowness of stature, and excessive length of arm—have become modified by miscegenation or the influences of environment.

The resemblances in culture of the Indian Negrito with the cognate races to the east and south-east of the Peninsula are too striking to be accidental. The

Kadirs of Madras climb trees like the Bornean Dayaks, clip their teeth like the Jakun of the Malay Peninsula, and wear curiously ornamented hair-combs like the Semang of Perak, among whom they serve some obscure magical purpose. The Negrito type deserves special examination in relation to the recent discovery of Pygmies in New Guinea, and the monograph on the Pygmy races in general by Dr. P. W. Schmidt, who regards them as the most archaic human type, from which he supposes the more modern races were developed, not by a process of gradual evolution, but *per saltum*. If there be any force in these speculations he is justified in expressing his conviction that the investigation of the Pygmy races is, at the present moment, one of the weightiest and most urgent, if not the most weighty and most urgent, of the tasks of ethnological and anthropological science.

This Negrito stock was followed and to a considerable extent absorbed by that which is usually designated the Dravidian. The problem of the origin of this race has been obscured by the unhappy adoption of a linguistic term to designate an ethnical group, and its unwarrantable extension to the lower stratum of the population of northern India. At present the authorities are in conflict on this, the most important question of Indian ethnology. One school denies that this people entered India from the north or north-west on the ground that the immigration of a dolichocephalic race from a brachycephalic area is impossible, and insists that the distinction between the so-called Dravidians and Kolarians is linguistic, not physical. The other theory postulates the origin of the Dravidians from the north-west, that of the Kolarians from the north-east; and avoids the difficulty of head form by referring the Dravidians to one of the long-headed races of central or western Asia or north Africa, or by suggesting that their skull form has become modified on Indian soil by environment or miscegenation.

Recent investigations, archæological or linguistic, throw some new light on this complex problem. Sir T. Holdich, in his recent work 'The Gates of India,' asserts that Makrán, the sea-board division of Baluchistan, is full of what he calls 'Turanian,' or Dravidian remains. He explains the position of the Brahui tribe in Baluchistan, on whom the controversy mainly turns, by assuming that while they now call themselves Mingal or Mongal and retain no Dravidian physical characters, the survival of their Dravidian tongue is due to the fact that it is their mother-language, preserved by Dravidian women enslaved by Turo-Mongol hordes. Relics of the original Dravidian stock, he suggests, may be found in the Ichthyophagi, or fish-eaters, whom Nearchus, the admiral of Alexander the Great, observed on the Baluchistan coast, living in dwellings made of whale-bones and shells, using arrows and spears of wood hardened in the fire, with claw-like nails and long shaggy hair, a record of the impression made upon the curious Greeks by the first sight of the Indian aborigines.

In the next place, inquiries by Dr. Grierson in the course of the Linguistic Survey prove that what is called the Mon-khmer linguistic family, which preceded the Tibeto-Burman in the occupation of Burma, at one time prevailed over the whole of Further India, from the Irawadi to the Gulf of Tongking, and extended as far as Assam. To this group the Munda tongue spoken by some hill tribes in Bengal is allied; or, at least, it may be said that languages with a common substratum are now spoken not only in Assam, Burma, Annam, Siam, and Cambodia, but also over the whole of Central India as far west as the Berars. 'It is,' says Dr. Grierson, 'a far cry from Cochin-China to Nimár, and yet, even at the present day, the coincidences between the language of the Korkus of the latter district and the Annamese of Cochin-China are strikingly obvious to any student of language who turns his attention to them. Still further food for reflection is given by the undoubted fact that, on the other side, the Munda languages show clear traces of connection with the speech of the aborigines of Australia.' The last assumption has been disputed, and it is unnecessary to discuss this wider ethnical grouping. Though identity of language is a slippery basis on which to found an ethnological theory, it seems obvious that the intrusive wedge of dialects allied to the Mon-khmer family implies that the Central Indian region was at one time occupied by immigrants who forced their way through the eastern Himalayan passes, their arrival being antecedent to the migration which introduced the Tai and Tibeto-Burman stocks into Further India.

When the solution of this problem is seriously undertaken under expert guidance, the first step will be to make an exhaustive survey of the group of

forest tribes, from the Santáls and Pahárias on the east, passing on to the Kols and Gonds, and ending with the Bhíls on the west. At present our information of the inter-relations of these tribes is fragmentary, and their superficial uniformity does not exclude the possibility that they represent more than one racial element. It will also be necessary to push inquiry beyond the bounds of the Indian Empire, and, like the trigonometrical surveyor, to fix the base line as a datum in India, and extend the triangulation through the borderlands. It is in these regions that the ethnological problems of India await their final solution. Many of these countries are still beyond our reach. Until the survey of the routes converging at Herat, Kabul, or Kandahar is complete the extent of the influence of the western races—Assyrian, Babylonian, Iranian, Arab, and Greek—cannot be determined. Recent surveys in Tibet have thrown much light on that region, but it is still only very partially examined. In Nepal the suspicious native government still bars the way to the Buddhist sites in the Tarai and the Nepal valley, and thus a wide chapter in the extension of Hindu influence beyond the mountain range remains incomplete.

The second great problem is the origin and development of caste. We have yet to seek a definition which will cover the complex phases of this institution, and effect a reconcilement between the views of Indian observers who trace it to the clash of races or colours, and that of the sociologists, who lay little stress on race or colour and rely more upon the influence of environment, physical or moral. We must abandon the insular method which treats it only in relation to India, and ignores the analogous grouping of rank and class which were prepotent in western Europe and elsewhere, and are now slowly losing ground in the face of industrial development. It is by the study of tribes which are on the borderland of Hinduism that we must look for a solution of the problem. The conflict of the Aryan and aboriginal culture, on which the religious and social systems of Hinduism were based, is reproduced in the contact between modern Hinduism and the forest tribes. Since the Hindus are the only members of the Aryan stock among whom we find endogamous groups with exogamous sections, the suggestion of Professor Frazer that they may have borrowed it from the non-Aryans gains probability. The Dravidians within the Indian totemic area have worked out an elaborate system of their own, which is well described in the recent survey of the Malayans by Mr. F. T. Richards. How far this is connected with their preference for mother-right and their strong family organisation, of a more archaic type than the joint family of the Aryans, is a question which deserves examination. The influence, again, of religion must be considered, and this can be done with the most hopeful results in regions like eastern Bengal, where a people who have only in a very imperfect way adopted Hinduism are now being converted wholesale to Muhammadanism.

Again, when we speak of the tribe in India, we must remember that it assumes at least seven racial types, ranging from the elaborate exogamous groups of the Rajputs to the more archaic form characteristic of the Baloch and Pathán tribes of the western frontier, attached to which are alien sections affiliated by the obligation to join in the common blood-feud, which in process of time develops into a fiction of blood-brotherhood. Thus among the Marri of Baluchistan we can trace the course of evolution: admission to participate in the common blood-feud, admission to participation in a share of the tribal land, and finally admission to kinship in the tribe.

This elasticity of structure has permitted not only the admission of non-Aryan tribes into the Rajput body in modern times, but prepares us to understand how the majority of the Rajputs were created by a similar process of fusion, the newcomers being known as the Gurjaras, who entered India in the train of the Huns in the fifth or sixth century of our era. The recognition of this fact, by far the most important contribution made in recent times to the ethnology of India, is due to a group of Bombay scholars, the late Mr. A. M. T. Jackson, whose untimely death at the hand of an assassin we deeply regret, and Messrs. R. G. and D. R. Bhandarkar. Mr. D. R. Bhandarkar has recently proved that a group of these Gurjara Huns, possibly the tribal priests or genealogists, were admitted first to the rank of Brahmans, and then, by a change of function, of which analogies are found in the older Sanskrit literature, becoming Rajputs, are now represented by the Guhilots, one of the proudest septs. This opens up a new

view of tribal and caste development. Now that we can certainly trace the blood of the Huns among the Rajput, Jat, and Gujar tribes, a fresh impulse will be given for the quest of survivals in belief and custom connecting them with their central Asian kinsfolk.

In what I have said I have preferred to speculate on a programme for work in the future rather than dwell upon the progress which has been already made. In the sphere of religion we have passed the stage when, as Professor Max Müller said, 'the best solvent of the old riddles of mythology is to be found in the etymological analysis of the names of gods and goddesses, heroes and heroines,' or when the 'disease of language' theory was generally accepted. The position, in fact, has completely changed since Comparative Religion has adopted the methods of Anthropology. The study of myths has given way to that of cults, the former being often only naïve attempts to explain the latter. India offers wide fields for inquiry by these new methods, because it supplies examples of cult in its most varied and instructive phases. The examination of Hinduism, the last existing polytheism of the archaic type, is likely to explain much hitherto obscure in the development of other pantheons. It is no longer possible to refer the complex elements of this or any other group of similar beliefs to a single class of physical concepts. The sun, the dawn, the golden gates of sunset, or the dairy no longer furnish the key which unlocks the secret. It is by the study of the Animism, Shamanism, or Magic of the lower tribes that Hinduism can be interpreted. This analysis shows that behind the myths and legends which shroud the forms of the sectarian gods the dim shape of a Mother-goddess appears, at once chthonic or malignant because she gives shelter to the dead, and beneficent because she nurtures the sons of men with the kindly fruits of the earth. Beside her, though his embodiment is much less clearly defined, stands a male deity, her consort, and by a process of magic, mimetic, sympathetic, or homœopathic, their union secures the fertility of the animal and vegetable creation.

Much, however, remains to be done before the problems of this complex polytheism can be fully solved. The action of archaic religions, as has been well said, 'takes place in the mysterious twilight of sub-consciousness'; and the foreign observer is trammelled by the elaborate system of tabu with which the Hindu veils the performance of his religious rites. This feeling extends to all classes, and the ceremonial of the jungle shrines is as little open to examination as the *penetralia* of the greater temples. The great army of mendicant friars jealously conceals the secrets of its initiation, rites, and beliefs, and this field of Indian religious life remains practically unworked. Much may be done by the training of a body of native observers who are not subject to the tabu imposed upon the foreigner. Here the difficulty lies in the contempt displayed by the higher educated classes towards the beliefs and usages of the lower tribes. There are some indications that this feeling is passing away, and in recent years much useful ethnological work has been done by native scholars.

The problems of ethnology, so far as they are concerned with the origin of prehistoric races and their relation to the existing population, are more or less academic. Ethnography, which examines the religious, cultural, and industrial conditions of the people, has more practical uses. At the present time it is incumbent upon us to preach, in season and out of season, that the information which it is competent to supply is the true basis of administrative and social reform. If, for example, we were now in possession of the facts which an anthropometrical survey of our home population would supply, many of our social problems would assume a clearer aspect. Such, for instance, are the questions of degeneration due to slum life and malnutrition, the influence of alcoholism on industrial efficiency, the condition of dangerous and sweated industries, and that of the aliens settled in our midst. It is characteristic of the genius of the English people that, while we are not yet prepared to admit the need of such a survey, the provision of medical inspection and relief for children in elementary schools will soon render it inevitable.

This is more clearly the case in those regions where a large native population is controlled by a small European minority. The Negro question in America teaches us a useful lesson, applicable to native races in most parts of the Empire. In India, whenever the Government has made really serious mistakes, the failure has been due to ignorance or disregard of the beliefs or prejudices of the subject

people. A little more than a century ago a mutiny of native troops at Vellore was due to injudicious attempts to change a form of headdress which they believed to be a symbol of their religion or caste; ignorance of the condition of the Santáls allowed them to be driven to frenzy by the extortions of moneylenders which culminated in a serious outbreak; the greased cartridges of the Great Mutiny, and the revolt against measures, adopted in defiance of native feeling, to check the plague epidemic, teach a similar lesson.

In India at the present time 'the old order changeth, yielding place to new'; and at no period in the history of our rule was it more necessary to effect a reconciliation between the foreigner and the native. While the tabus of marriage relations and commensality will for an indefinite period prevent the amalgamation of the races, much of the present disquiet is due to ignorance and misunderstanding on both sides. The religious and social movements now in progress deserve the attentive study of the British people. In religion various attempts are being made to free Hinduism from some of its most obvious corruptions, to harmonise Eastern and Western ideals, and to elevate the former so as to enable them to resist the pressure of the latter. Such is Vedantism, a revival of the ancient pantheistic philosophy, which not only claims supremacy in India, but asserts that its mission is to replace the dying faiths of the Western world. The spread of monotheism, as represented by Bhagavata beliefs, is equally noteworthy; and the effect of the revival of the cults of Ganpati, god of luck, and of Savaji, the Mahratta hero, on the political situation in the Deccan deserve the most careful consideration.

The social movement is the result of that fermentation which is in progress among the subject peoples in many parts of the world. While the educated Indian claims social equality with the foreigner, he is occupied with a serious problem at his own doors. The degraded castes, popularly called the 'untouchables,' are revolting against the obloquy which they have long endured at the hands of the higher races. Many of them have sought relief by joining the Christian or Muhammadan communities, and the process of conversion is so remarkable as to excite the surprise and alarm of the orthodox classes. Measures have been designed to improve their almost intolerable position. It remains to be seen how far any concessions which are likely to satisfy them can be reconciled with the ideals of the caste system.

It is true that the people of India prefer to celebrate many of their religious and social rites free from observation of the foreigner, and that there are forbidden chambers in the Oriental mind which no stranger may enter. But the experience of those best qualified to express an opinion is that a sympathetic interest in the religious and social life of the people, so far from tending to increase the existing tension, is a valuable aid towards the promotion of mutual goodwill and sympathy. Orthodox native States not only show no aversion to ethnographical inquiry, but are themselves actively engaged in such surveys. Even the Rajputs, who ordinarily display little taste for scientific work, are beginning to undertake the collection of the bardic chronicles which embody their tribal folk-lore and traditions.

When the divergencies in the beliefs and institutions of the foreigner and the indigenous races are realised and understood, a compromise must be effected, each side discarding some hereditary prejudices—the Hindu that aversion to the manners and customs of the European which is the chief barrier to the promotion of intercourse between the races; the European that insularity of thought which makes it difficult for him to understand all that is valuable in novel types of belief and culture, as well as that lack of imagination which inclines him to exaggerate what seems to him intolerable in the economical condition, the social organisation and beliefs of races whose environment differs from his own.

Anthropology has thus a practical as well as a scientific side. The needs of inquirers whose interest mainly lies in the investigation of survivals and in the stages of evolution in culture and belief can, as I have endeavoured to show, be met only by the adoption of improved methods of inquiry and a more rigorous dissection of evidence. Unfortunately the inadequate resources of the societies devoted to the study of man, as contrasted with the extent of the sphere of inquiry and the importance of the savage or semi-savage races as factors in the progress of the Empire, prove that the practical value of anthropology is as yet

only imperfectly realised. If its progress is to be continuous we must convince the politician that it has an important part to play in the schemes in which he is interested. Thus it is certain that in the near future the relations between the foreigner and the native races will demand the increasing attention of statesmen at home and abroad. Here anthropology has a wide field of action in the examination of the causes which menace the very existence of the savage; of the condition of the mixed races, like the Creole or the Eurasian; of the relations of native law and custom to the higher jurisprudence; of the decay of primitive industries in the face of industrial competition. One of its chief tasks must be the examination of the physical and moral condition of the depressed classes of our home population, and the effect of modern systems of education on the mind and body of the child. It will thus be in a position to assist the servants of the State to meet the ever-increasing responsibilities imposed upon them; and it will help to dispel the ignorance and misconceptions which prevail even among the intelligent classes in this country in regard to the condition of the native races, who, by a strange decree of destiny, have been entrusted to their charge. By such practical contributions to the welfare of humanity it will not only secure the popular interest which is a condition of efficiency, but engage the ever-increasing attention of those to whom its scientific side is of paramount importance.

The following Papers were then read :—

1. *The People of Cardiganshire.*[1]
By Professor H. J. Fleure, *M.A., D.Sc., and* T. C. James, *M.A.*

An anthropometrical survey of the Welsh population has been in progress for some years, and detailed observations of about 1,500 adults have been taken. The observations include the facts of descent, pigmentation, features of head and face, fourteen measurements in the head region, and determination of standing height and length of limbs, and all the facts for each individual are recorded on a card which is retained for further analysis. It is worthy of note that the only measurements which have been found useful for analytical work thus far are those of head-length, head-breadth, bizygomatic-breadth, bigonal-breadth, auriculo-nasal radius and auriculo-alveolar radius, in addition to those of stature and limbs; and the further work of the survey will be lightened by restricting attention to these features and notes on family history, pigmentation, and other features. The present paper is a first report, and deals with the characteristics of 520 adult males whose family history, so far as it is known, shows that they belong exclusively to Cardiganshire, though that name is not used in the exact sense, but is held to denote the region bounded by the river Dyfi, the Plynlimmon anticline, Mynydd Prescely, and the sea.

The foundation of the population is of Mediterranean type, characterised by great length and size of head, dark brown to black hair, slight prognathism, stature slightly below the average (1,671 mm.), largely through the absence of very tall individuals, and a somewhat high ratio of length of leg to stature. All the characteristics are shown most markedly among the men with black hair, dark fresh skin, and brown eyes, whose head indices are about 74·6. The length of head seems due mainly to a marked occipital projection. As one goes from these individuals to others with hair dark brown instead of black, one finds that the prognathism and the occipital projection decrease and disappear, the latter change involving a shortening of the head and a consequent rise of head index. The best types are undoubtedly those from the remoter valleys in the mountain sides and those from the deep valley of the Teify and its tributaries around Llandyssul.

There are scattered individuals with dark pigmentation and a head index 80·5. These usually have the head short, and they are more numerous along the open coast from Llanrhystyd to New Quay than elsewhere.

The distribution of the fair-haired people is most interesting. There is a sprinkling of them throughout the county with a cluster of the narrower-headed

[1] To be published in *Liverpool Annals of Archæology and Anthropology.*

men (76·8) at Newcastle Emlyn, some distance up the Teify. They occur in large numbers along the open coast from Llanrhystyd to New Quay, and extend eastward up the valley of the Wyre and, further south, across the low hills of Mynydd Bach into the centre of the county, around Pontrhydfendigaid, Tregaron and Llanddewi Brefi, and here it is the individuals with an index of 79·80 who predominate, while their features are more strongly developed than in the case of the Newcastle Emlyn men. They are opisthognathous and slightly taller (1,699 mm.) than the Mediterranean people, but include several individuals about 1,800 mm. in height, the average being brought down by occasional very short individuals (below 1,600 mm.). The fair type becomes decidedly rarer inland north of the Wyre, and this is interesting, as that valley forms one of the most marked dialect boundaries in Wales, and the hills above it have a remarkable series of early earthworks which need further study.

Among the fair people, as among the dark, increase of head index is correlated with a decrease of head length, which is continuous except for a break due to a number of exceptionally big men (average stature, 1,724 mm.) with index 78·9. Here and there, and notably around Tregaron, there are men with index about 78·81, red hair, florid features, large foreheads, prominent zygomatic arches, and often an insinking of the cheek. Our observations point to their being the result of crossing between fair and dark types, but this opinion is stated with reserve for the present.

A similar account of Merionethshire will be ready, we hope, before long, and similar work is in progress for Carnarvonshire and Carmarthenshire, while numerous observations have been collected for other counties and a definite campaign in Glamorganshire is being organised.

2. *The People of Egypt.*

By Professor G. Elliot Smith, *M.A., M.D., F.R.S.*

Recent experience has shown that no attempt to reconstruct the history of man in Egypt is likely to yield other than wholly inconclusive, if not actually confusing and misleading, results, unless it is based upon the study of the physical characters (and *not* of mere measurements) of large series of accurately dated human remains of people of various social grades, representative of every historical period, and of each of the three primary subdivisions of the lower Nile Valley, viz., Lower Egypt, Upper Egypt, and Lower Nubia.

In the present state of our knowledge it would be idle to discuss the origin of the Predynastic Egyptian population beyond stating that the people show undoubted affinities with the so-called 'Mediterranean Race' as well as with the Arabs, and that they must have been settled in the Nile valley for many ages before they constructed the earliest prehistoric graves known to us, for their peculiarly distinctive culture, their arts, their mode of writing, and their religion were certainly evolved in Egypt.

But even before the end of the Predynastic period a slight change in the physical traits of the population can be detected; although it is not until more than four centuries later, *i.e.*, until the time of the Third Dynasty, that the modification of the physical type becomes sufficiently pronounced to afford unmistakable evidence of its significance. For then the three Nile territories under consideration had each its own distinctive people: Lower Nubia, a population essentially identical with the Predynastic Egyptian, but slightly tinctured with negro; Lower Egypt, the descendants of the Predynastic Egyptians, profoundly modified by admixture with alien white immigrants, who entered the Nile valley *via* the Delta; and Upper Egypt, protected by its geographical position from the direct effect of either of these foreign influences, was being subjected to the indirect influence of both by the intermingling of its people with those of Nubia and Northern Egypt.

In the time of the Middle Kingdom this double racial influence became much more pronounced in the Thebaid, and the effect of the white immigration became almost as pronounced there as it had been in Lower Egypt in the times of the Pyramid builders of the Old Kingdom. The Nubian element also became more significant, the influx consisting at various times of slaves, mercenaries, and

perhaps also invaders, not to mention the slow but steady percolation into Egypt of a negroid element resulting from the secular intermingling of neighbouring peoples. Thus began that graduation of racial characters in the Nile valley, ranging from the Levantine white population of Alexandria to the negro of the Sudan, which has persisted until the present day, and is displayed even in the measurements of thirty thousand modern Egyptian men, which are now being examined by Mr. J. I. Craig.

It is not yet possible to express a positive opinion as to the source of the white immigration into the Delta, which first reached significant proportions in the times of the Third and Fourth Dynasties; but, from evidence which I have recently collected, it seems probable that the bulk of it came from the Levant. It is most likely, however, that there was a steady influx into the Delta of people coming both from east and west, and that their percolation into Egypt was so gradual as not to disturb violently the even flow of the evolution of the distinctive Egyptian civilisation. Nevertheless, it is perhaps not without significance, especially when we take into account the simple-minded, unprogressive, and extremely conservative character of the real Egyptian, to note that none of the greatest monuments were constructed nor the most noteworthy advances made in the arts of the Egyptian civilisation, except on the initiative of an aristocracy, in the composition of which there was a considerable infusion of non-Egyptian blood. From the times of the Pyramid builders until the present day Egypt's rulers have probably never been of undiluted Egyptian origin.

3. *The Excavations at Memphis.* *By* Professor W. M. Flinders Petrie, *D.C.L.*, *F.R.S.*

4. *A Neolithic Site in the Southern Sudan.*[1] *By* C. G. Seligmann, *M.D.*

The country between the White and the Blue Niles south of Gezireh consists of a level plain from which project isolated masses of rock. In the dry season water is scarce, springs being confined to the flanks and feet of the hills. Jebel Gule, which lies about fifty miles due west of Renk, on the White Nile, is over 1,000 feet high and perhaps three or four miles in circumference, and in the old days it was the governing centre of a considerable population.

At its foot there are two settlements of people who call themselves Fung, but are generally known to their neighbours as Hameg; they profess Islam and speak Arabic, but keep up a number of non-Muslim customs, and the majority of them still speak a language which they say they all spoke before the sixteenth century—the date which they give for their conversion to the Faith.

Worked stone implements, which show that three industries were carried on, were found at Jebel Gule. These include (1) a neolithic adze-head and hammer-stone, both of black basalt, while many grooves on the rock show where tools such as the adze-head had been ground. There does not, however, appear to be any basalt on the hill. (2) A large number of pygmy implements, which for the most part consisted of one of the varieties of quartz. A few of horn-stone were also found. (3) A large number of implements of horn-stone or of a horn-stone breccia cemented with chalcedony. These are for the most part scrapers, but blades and discs were also found, the latter resembling the palæolithic implements found in Suffolk and elsewhere. There is also a single specimen of an implement which might be considered a small palæolithic *coup de poing*.

All these implements were picked up on the surface, or covered only with a thin layer of blown sand, and there is therefore no certain indication of their age. But in spite of the palæolithic form of some of the specimens, the nature of the site and the small amount of weathering are in favour of their being neolithic. In any case, they are of an entirely different type from the worked stones which have hitherto been found in the Sudan in association with Meroitic or other historic civilisations.

[1] Published in *Journal of Royal Anthropological Institute*, vol. xl., part 1, January to June 1910.

5. *Native Pottery Methods in the Anglo-Egyptian Sudan.*[1] *By* G. W. Grabham, *M.A.*

With the exception of a stretch of country along the Nile between Khandak and Kerma, in Dongola Province, the use of the wheel is unknown in the Sudan. Three distinct methods of shaping wares by hand are in use, and may be detailed as follows :—

1. The manufacture of bormas, gudus, &c., by men, often of the Shaigia tribe of Dongola. The mud is mixed with a large proportion of dung to prevent cracking on drying. The mouth and upper part of the jar are first formed and placed to dry in a special way. When the mouth is sufficiently hard to stand the weight of the vessel the lower part is finished by drawing out the surplus mud left for the purpose. The wares are baked in a flask-shaped kiln, often hollowed out of the ground.

2. The manufacture of bormas and basins by women, often belonging to the pilgrims who cross the Sudan from the west on their way to Mecca. The clay used is fairly pure, but a small amount of chopped grass is mixed in during the formation of the wares. These are shaped by pressing the clay into a hollow in the ground, and by this means an almost spherical vessel is produced, with a hole only large enough to admit the arm of the worker. The neck is finished off by hand, and the wares are built up into a low pile with dung and baked by setting fire to the heap.

3. The manufacture of gabanas. This is carried on in Omdurman, but the home of the industry is probably farther east. Two cup-shaped basins are formed, and, with the aid of a hole cut in one, the two are joined together. A spout and handle are added before the vessel is scraped, polished, and ornamented. The baking is done by building the wares into a heap with dung. These gabanas, or coffee-pots, are beautifully symmetrical and remarkable for the thinness of the ware.

6. *Note on some Anatomical Specimens of Anthropological Interest, prepared by means of the New Microtome of the Cambridge Scientific Instrument Company.* *By* W. L. H. Duckworth, *M.A., M.D., Sc.D.*

The new microtome of the Cambridge Scientific Instrument Company provides a means of preparation of anthropological material possessing great interest. The instrument has been carefully tested at the Anatomy School at Cambridge, and some of the preparations yielded by it have been mounted as lantern-slides. The instrument is fully described in the Instrument Company's list, and it will therefore suffice in this place to state that it combines some of the valuable mechanism of the well-known "rocking" microtome with great rigidity and uniform action. The experiments above mentioned show that the instrument will cut good sections, of an area of ten square inches at least and of material of very varying density, which always presents special difficulties. In a section of the human leg (of an adult man) may be seen tissues so distinct in consistency as bone, tendon, and muscle.

Other specimens shown included the following examples :—

The human larynx cut in transverse horizontal section.

The larynx of a large adult orang-utan in vertical coronal section.

The human tongue in vertical coronal section at various levels.

The chief point emphasised is the importance of such preparations in elucidating the details of structure when the human tissues are compared with corresponding parts of the larger mammalia, particularly anthropoid monkeys.

FRIDAY, SEPTEMBER 2.

Joint Discussion with Section L on Research in Education.

[1] To be published in the *Journal of Cairo Scientific Institute.*

MONDAY, SEPTEMBER 5.

The following Papers and Reports were read :—

1. *Archæological Activities in the United States of America. By* Miss Alice C. Fletcher.

This paper opened with a brief account of the foundation of the Peabody Museum of American Archæology and Ethnology, Harvard University, the first institution in America founded for anthropological study, and recited its activities during the current year.

A short account of the Government's movements, which finally led to the establishment of the Bureau of American Ethnology, its scope, and its work in the past and at the present time, followed.

The establishment of the Field Museum, Chicago. The extensive and valuable contribution of the University of California. The Columbia University of New York. The University of Pennsylvania, Philadelphia. The Anthropological Department of the Natural History Museum of New York City. The Brooklyn Institute, New York. The South-West Museum, Los Angeles, California. The Denver Museum, Colorado. The Academy of Sciences, Davenport, Iowa. The founding of the Archæological Institute of America; its schools at Athens, Rome, and Jerusalem. The formation of the Committee on American Archæology. Development of interest in the American field among the various affiliated societies of the institute. The unification of this interest by the appointment of Dr. Edgar L. Hewett as director of American Archæology. The establishment of the School of American Archæology authorised. The generous offer of the State of New Mexico of the old 'Palace' building, erected in 1608, at Santa Fé, for the use of the school and its museum. The present field activities of the school in the south-western parts of the United States and in Central America. The advantages the school offers to research students.

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2. *A Group of Prehistoric Sites in S.W. Asia Minor. By* A. M. Woodward, *M.A., and* H. A. Ormerod, *B.A.*

In all nineteen prehistoric mounds were examined, extending from the plain of Elmali (in North-East Lycia) to Lake Kestel, in Pisidia, and by way of Lake Karalitis and the plain round Tefenni to Kara-Eyuk-bazar, at the foot of Kazyk-Bel, in Southern Phrygia. The sherds found on the mounds consisted mainly of a red, hand-polished ware assignable to the Bronze Age, with rarer fragments of a black polished ware. Some of these sherds may possibly be of neolithic origin. With these was found on certain sites a large quantity of painted fragments, showing analogies on the one hand with Cappadocian pot-fabrics, and again with those of the Early Cypriote Iron Age. This pottery would seem, however, for the most part independent of Ægean influence or importation, and fragments of obsidian obtained are apparently not of Melian origin. One of the larger mounds at Tchai Kenari, partly excavated for brick-earth, provided a rough sectional view of stratification to a depth of eight metres, with three superimposed floor-levels. On another mound a few miles to the west were the remains of a megalithic house of rectangular plan, with an outer-walled court-yard. This building is probably to be dated not earlier than the beginning of the Iron Age.

The full extent of this civilisation is not yet determined, and generalisation would be premature; it would appear, however, that it is not merely a south-westerly extension of the prehistoric Cappadocian culture, but largely independent of it. In view of the suggested equation Shakalasha=Sagalassi, it would be interesting if these early settlements, traced hitherto to within a day's journey of Sagalassus, should prove to be the home of the Shakalasha whose name appears on the Merenptah inscription of the XVIIIth Dynasty.

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3. *Excavations in Thessaly*, 1910.
By A. J. B. Wace, *M.A.*, *and* M. S. Thompson, *B.A.*

The sites chosen for this year's work were Tsangli, in Central Thessaly, about midway between Pharsala and Velestino, and Rachmani, half-way between Larissa and Tempe.

At Tsangli the work lasted from March 21 to April 12, and was much interrupted by bad weather, rain, and snow. We sank several shafts from the top of the mound to virgin soil to test the stratification, and also on the east side cleared two small areas, where we found the remains of neolithic houses. The mound is about two hundred metres long and two hundred and ten wide, and the deposit in the highest part is about ten metres thick. The results of the stratification of the pottery will be mentioned in connection with that at Rachmani. The houses are very interesting; three were found built one over another. They are square in plan and have as a rule two internal buttresses in each angle, and all three belong to the latter part of the first neolithic period, but the earliest house is slightly more primitive in plan, and has only five internal buttresses instead of eight. The first two houses were abandoned, but the third had been destroyed by fire, and in it were several good vases and twelve celts. In the second a store of over sixty terra-cotta sling bullets was found. Another house had been destroyed by fire towards the end of the first neolithic period and was never afterwards rebuilt. This house is large and divided across the middle by a row of wooden posts. It had eight internal buttresses and a door in the middle of the south wall. A large number of vases were found in this house, many celts, and some interesting terra-cotta statuettes. In general the excavation was very rich in stone implements. We found about seventy celts, including some fine examples; also between twenty and thirty good terra-cotta statuettes were discovered. Of these the male figures, which are rare in Thessaly, are remarkable for their phallic character and the female figures for their marked steatopygy.

At Rachmani the excavation lasted from April 14 to the end of the month. The mound is about 112 metres long and 95 wide, and the deposit is eight metres thick. A careful observation of the stratification of the shafts sunk in this mound and a comparison of it with the results from Tsangli and other sites enable us to divide the prehistoric remains of Thessaly into four periods: (1) Neolithic—marked by the presence of red on white painted pottery; (2) Neolithic—marked by the presence of Dhimini and kindred wares; (3) Sub-Neolithic—in this period falls the remarkable encrusted ware, but while stone tools are common, no trace of bronze has yet been found in deposits of this period; (4) Chalcolithic—in this period the pottery is unpainted, and the latter part of it is apparently contemporaneous with late Minoan II. and III., for to it belong the tombs of Sesklo, Dhimini, and Zerelia, and the L.M. III. and Minyan ware found at these and other sites. It is also noticeable that at Rachmani in the top of the deposit of the fourth period we found many sherds of L.M. III. ware mixed with fragments of primitive geometric pottery like that found in early iron-age tombs at Marmariani and Theotokou. In the deposit of the third period we found an oblong one-roomed house with the southern short side rounded. In it were three good specimens of encrusted ware, a series of four figurines with rough terra-cotta bodies and painted stone heads, and a large store of carbonised wheat, pease, lentils, figs, &c. Another house of the same type, with a slightly more developed plan, was found in the deposit of the fourth period, but apart from a few stone implements nothing was found in it. The only other finds worth separate mention are three fragments of bronze found in the deposits of the fourth period and a tomb that contained one L.M. III. vase and two inferior gems.

We now propose to close our prehistoric excavations in Thessaly for the present and to publish a book on the subject, which is in active preparation. Later next season we hope to excavate a prehistoric site in Macedonia and to resume our exploration of that country, making a special study of the prehistoric

4. *Report on Excavations on Roman Sites in Britain.*—See Reports, p. 227.

5. *Report on Archæological and Ethnological Researches in Crete.* See Reports, p. 228.

6. *The Work of the Liverpool Committee for Excavation and Research in Wales and the Marches.*[1] *By* Professor R. C. BOSANQUET.

7. *The Excavations at Caerwent, Monmouthshire, on the Site of the Romano-British City of Venta Silurum, in* 1909–10. *By* T. ASHBY, *M.A.*, *D.Litt.*

The excavations of 1909 were at first carried on in the north-east corner of the city. Important additions were made to the plan, which was found to preserve the regular arrangement noticed elsewhere. Remains of several houses were discovered, and also those of a building more than once altered, which, it is possible, are those of a Christian church. Later in the season attention was devoted to the completion of the excavation of the central insula in the north half of the city, which contains the forum and basilica. The greater part of it had been excavated in 1907,[2] but it was found possible in 1909 to make arrangements for the exploration of the western portion of the basilica and the western side of the forum. The block was found to be perfectly rectangular, being thus more carefully laid out than most of the other buildings at Caerwent. The basilica had no apse at either end, but at each end of the north aisle and nave was a chamber of the same width as theirs, while at each end of the south aisle there was an entrance from the streets which ran outside the forum on the east and west. The south aisle had an open arcade towards the forum, which was surrounded on the other sides (with the possible exception of the west side) by an ambulatory and shops; and the open area was drained by a large box-drain.

The excavations of 1910 were conducted on the south side of the high road, which coincides with the ancient road through the centre of the town. They resulted in the discovery of a few houses, one of them much altered, so that its original plan is difficult to make out. In the centre of it is a well-constructed cellar. More than a hundred skeletons have been discovered here. The burials are obviously of post-Roman date, the walls of the house having been partially destroyed when the graves were dug.

8. *Excavations at Hagiar Kim and Mnaidra, Malta.* *By* T. ASHBY, *M.A.*, *D.Litt.*

The excavations which were carried out by the Government of Malta under my direction during the month of June at the well-known megalithic buildings (in all probability sanctuaries) of Hagiar Kim and Mnaidra had a twofold object: it was desired to ascertain whether in the original excavations of both buildings in 1839 and 1840, and in the supplementary excavations of the former in 1885, the ground-plan had been completely discovered, or whether there were any additions to be made to it; and also, inasmuch as previous explorers had unfortunately almost entirely neglected to preserve the small objects, and especially the pottery, which it was obvious that they must have found, to see whether it were not possible to remedy the deficiency to some extent by the recovery of sufficient pottery at any rate for the determination of the date of the structure. In the course of ten days' work at each building satisfactory results were arrived at in both these respects. It was found that in front of the façade both of Hagiar Kim and of the lower building at Mnaidra there was a large area roughly paved with slabs of stone. This was also the case at

[1] To be published in the *Liverpool Annals of Archæology and Anthropology.*
[2] See Report of the Dublin Meeting, 1908, p. 857.

a building of a similar nature excavated in 1909 on the hill of Corradino, and seems to have been a regular feature. No further additions (except in small details) were made to the plan of Hagiar Kim, but at Mnaidra it was found that besides the two main parts of the structure there were some subsidiary buildings, which, though less massive, were of considerable importance; they were perhaps devoted to domestic uses, inasmuch as a very large quantity of pottery was found in them. It was also ascertained that the site for the upper part of the main building, which is undoubtedly later in date than the lower, was obtained by heaping up against the external north-east wall of the latter a mass of small stones so as to form a level platform, instead of by cutting away the side of the rocky hill upon the slope of which Mnaidra is situated.

In both buildings there were places in which the soil had not yet been completely cleared away, and chambers in which the ancient floors of pounded limestone chips (locally called 'torba') still maintained their hardness after perhaps 4,000 years. It was here that small objects were found in considerable quantities—numerous fragments of pottery and of flint, but no trace of metal. The former corresponded absolutely with that found in the hypogeum of Halsaflieni (recently described in an interesting and well-illustrated little book by Professor T. Zammit, the curator of the Valletta Museum), and in the other megalithic buildings of the island; so that it seems clear that Hagiar Kim and Mnaidra, like the rest, belong to the neolithic period.

Under one of the earlier floors in Mnaidra a curious group of small votive terra-cottas was found.

A few examples were also found of the small stone pillars, often narrowed in the centre, which are common in the megalithic buildings of Malta, both in isolation and as supports to the cover-slabs of the dolmen-like niches which are so important a feature in these buildings. In either case Dr. Arthur Evans thinks that they must be treated as *baetyli*, or personifications of the deity. Dr. Albert Mayr, in his valuable book on "Prehistoric Malta," is of opinion that the round towers, of which some half-dozen exist in Malta, also belong to the prehistoric period; but in a final excavation at Torre Tal Wilgia, near Mkabba, we were not able to find any evidence in favour of this supposition, all the pottery which came to light belonging at the earliest to the Punic period.

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9. *Cup- and Ring-Markings and Spirals: some Notes on the Hypogeum at Halsaflieni, Malta. By* Rev. H. J. DUKINFIELD ASTLEY, *M.A., Litt.D.*

This hypogeum, or series of subterranean chambers, is one of the most interesting of the many prehistoric remains in the island of Malta. It has been thoroughly excavated, and has recently been described by Professor Zammit. An exploration of the chambers and an exhaustive examination of the human remains and the pottery and figurines accompanying them, both on the spot and in the museum at Valletta, confirm conclusions reached by Dr. Ashby and Mr. Peet (*Brit. Assoc. Rep.*, *Winnipeg*, 1909, p. 619), that the hypogeum is a monument of the late Neolithic Age of Mediterranean culture.

Three of the chambers have decorated roofs and walls, and a fourth has a series of decorations on both lintels of a fine double dolmen-shaped doorway. These decorations, in red paint, quite clear and distinct, though somewhat worn by time, consist of a number of cup- and ring-markings and spirals, finely executed and in great variety. The combination is not common in prehistoric Europe, though it is in Australia. It would seem to point to an infiltration of Bronze Age, or Mycenean, culture, superimposed upon the Neolithic culture of the earlier population towards the close of that age. It is native work, but the influence of Crete is seen.

TUESDAY, SEPTEMBER 6.

The following Papers and Reports were read :—

1. *Kava-drinking in Melanesia.* *By* W. H. R. RIVERS, *M.A., M.D.*

It is usually supposed that the practice of drinking the infusion of the root of *Piper methysticum* in Melanesia has been introduced from Polynesia, but there are many facts in favour of its being an indigenous Melanesian custom, or, if introduced, of far greater antiquity than other features of Melanesian culture which can be ascribed to Polynesian influence. In the Southern New Hebrides the infusion is called kava, and, so far as can be judged from published accounts, the method of preparing it resembles that practised in Polynesia. Here the practice may have been modified by Polynesian influence. In the Northern New Hebrides, the Banks and Torres Islands, on the other hand, there are indigenous names; the whole ceremonial of making and drinking the infusion differs fundamentally from that of Polynesia, and the use of the substance is closely connected with other social institutions. In many cases the use of kava has a clearly religious character.

The occurrence of kava-drinking in the Fly River region of New Guinea suggests that the distribution of the custom may at one time have been very wide, and that in the greater part of New Guinea and in Northern Melanesia it has been replaced by betel. It is easy to understand how substances always ready to hand for immediate use, such as the ingredients of the betel-mixture, should have displaced one requiring the special and prolonged preparation which is necessary in the case of kava. A good example of such displacement is to be found in the Polynesian island of Tikopia, where betel, almost certainly a comparatively recent introduction, has in everyday life entirely displaced kava, which is only used in the form of libations poured out at the graves of the dead and during various religious ceremonies.

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2. *A Sidelight on Exogamy.* *By* Miss ALICE C. FLETCHER.

Some of the theories as to the origin of this widespread custom were reviewed and objections stated. No one explanation of exogamy is possible at the present stage of our knowledge of the many and various peoples who practise it. Evidences as to the reason for the practice of this custom among the Omaha tribe and of five cognate tribes have been gathered during more than twenty years of study among them. The organisation of these tribes is based upon cosmic ideas, religious in character, and their influence can be traced in the arrangement of the kinship groups and in the custom pertaining to marriage, which explain why these people practise exogamy.

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3. *The Suk of East Africa.* *By* MERVYN W. H. BEECH, *M.A.*

The Suk, or Pôkwut, who live north of Lake Baringo, are of mixed origin, as proved by language, appearance, and anthropometry. They are akin to the Nandi, but there is a large aboriginal element. They were originally agriculturists, and their tribes are subdivided into totemic and exogamous clans. Their social system resembles that of the Nandi. There are a number of customs connected with marriage, birth, death, and inheritance. They have no chiefs, only advisers—*i.e.*, influential men with no real power. Cattle are their chief interest and food. Portions of slaughtered animals are distributed according to age and sex. There are many beliefs and customs connected with cattle. Great precaution is taken lest women touch men's food. Dress, weapons and ornaments, and dances differ entirely from those of the Nandi, but resemble those of the Turkana. The agriculturists have an elaborate system of land tenure and interesting customs connected with cultivation, industries, and hunting. Religion is vague. Comparison of customs connected with crime shows the hill tribes to

be the hardier people. The Suk language shows a large percentage of Nandi, a little Turkana, and a considerable amount of what is probably aboriginal. The absence of an article is the most noteworthy feature.

4. *Interim Report on Archæological Investigations in British East Africa.*—See Reports, p. 256.

5. *A Search for the Fatherland of the Polynesians.* *By* A. K. Newman.

6. *The BuShongo of the Congo Free State.*[1] *By* E. Torday.

The BuShongo, who most probably came originally from the Lake Chad region, inhabit the district of the Belgian Congo between the fork of the Sankuru and Kasai rivers. The BuShongo nation is composed of a number of sub-tribes, all under the rule of one great chief. They are well-built and fine in appearance; their movements are graceful. The genealogy of the royal house mentions 121 successive kings, of whom the first was Chembe (God), and his name was Bumba. Under the twenty-seventh ruler fire-making was revealed by God to a man named Keri-Keri, and at this time another man invented bark clothes. Shamba Bolongongo, the ninety-third ruler and the great national hero, was a patron of the useful arts, a legislator and philosopher, and in his youth a great traveller. After his accession to the throne he introduced the weaving of palm-cloth, embroidery, the use of tobacco, and the game of Lela, revised the Court hierarchy, and introduced official representatives of the various trades. He established monogyny, and in his reign wood-carving and embroidery reached the highest pitch.

The organisation of the government of the country as remodelled by Shamba exists to-day, though greatly weakened. The king in theory is absolute, but in practice his power is limited by two bodies—a higher, consisting of six male and two female dignitaries; and a lower, consisting of 120 male and fifteen female representatives. Above all these, and to a certain extent above the king, is the king's mother. Land belongs to the nation, and is held for it by the king. The BuShongo engage actively in trade.

To belong to the BuShongo nation it is sufficient that one parent should be BuShongo. Membership of a tribe and village is constituted by birth within that tribe and village. A man may not marry any woman for whom a term of relationship exists or who has the same totem. There is no fixed sum for the bride-price. The totem (Ikina Bari) is inherited from the father, and wives adopt the Ikina of their husbands. The Ikina of the mother is observed to a certain extent, but not transmitted beyond one generation.

The BuShongo believe in an all-powerful Creator called Chembe. He has little to do with the human race, and no actual worship is paid him. There are several kinds of magicians, each of whom has more or less different duties. The dead are exposed for a certain time before burial. During the exposure the relatives go into mourning and special food tabus are observed. The houses of the dead are left to decay.

Before emigration the staple food consisted of millet, bananas, and yams: the use of cassava was subsequently introduced from the West. The chief condiment is palm oil. The BuShongo are great smokers. They hunt with hounds, and near the great rivers fishing with wicker barriers, baskets, and traps is practised. The work of the household is distributed equally between the sexes. Men clear the ground, build the house, and hunt. Women till the soil, fetch the firewood, and cook. The men alone paddle, and have to provide the family with garments, which are made of palm fibre. All men, without exception, can weave.

[1] To be published in book form by the Terveuren Museum, Brussels.

7. *A Rare Form of Divided Parietal in the Cranium of a Chimpanzee.*[1] *By* Professor C. J. Patten, *M.A., M.D., Sc.D.*

Apart from the presence of groups of small wormian bones, division of the parietals in the anthropoids is a very rare condition. In M. le Double's comprehensive work on the variations of crania only one case of complete parietal division by a horizontal suture is recorded in his tables, which date back over fifty years. The first case was described by Johannes Ranke in 1899 in an adolescent female orang, one of 245 orang crania in the Selenka collection of the Munich Anthropological Institute. In the following year Aleš Hrdlička published a case in the *Bulletin of the American Museum of Natural History*, which divisions he claims to be 'not only the first complete divisions of the parietal observed in a chimpanzee, but are also unique in character, no divisions of the same nature having been observed before, either in man, or apes, or monkeys.' The case now described appears also to be one of complete division of both parietals, each by a horizontal suture running the entire length of the bones and joining the coronal with the lambdoid sutures. This case, however, is of further interest owing to the extraordinary way in which the upper segment of each bone is again subdivided, giving that part of the vault of the cranium, when viewed from above, the appearance of the counties of a map. Correlated with the condition there is a thinning out of the bones of the cranial vault, and reduction of the size and strength of the zygomatic arch and of many processes of the base of the skull. In weight this cranium is decidedly lighter than that of an average chimpanzee of its size.

8. *Report of the Committee to Organise Anthropometric Investigation in the British Isles.*—See Reports, p 256.

9. *The Bishop's Stortford Prehistoric Horse.* *By* Rev. A. Irving, *D.Sc., B.A.*

The author gave a general description of the conditions under which the skeleton was found. Details were given as to the condition of the bones, and the action upon them of organic acids while the quaternary pond, in which the animal was mired, was open to the air, and before it was buried under landslides from the hill. A chemical analysis has been made of one of the bones of the trunk in Sir William Ramsay's laboratory at University College. The bones have been compared with those of Neolithic Age at South Kensington and Jermyn Street; also with those from Newstead, near Melrose, of the Roman period. Close anatomical relations were given between the Stortford skeleton and bones discovered (*a*) in the neolithic deposits of Pomerania, (*b*) the Bronze deposits of Spandau, (*c*) the pile-dwelling site of the Starnberger See, (*d*) the river drift at Ilford, and (*e*) the pleistocene deposits of Grantchester. The vertebral formula is that of the zebra (Flower), and differs both from horses of the *Equus Prejwalskii* type and the Plateau type of Ewart. It is a lighter-limbed animal than Nehring's Remagen horse, though in its teeth it resembles that most closely. Upon the whole it seems to be a blend of the 'Forest' and the 'Plateau' types of Ewart. The evidence obtained on the site of its discovery was discussed, including a Holocene molluscan fauna (Woodward). The general conclusion seems warranted that the horse represents a race of post-Pleistocene times, as a survival into the Neolithic or Bronze Age, certainly not later than the La Téne age.

[1] To be published in full in *Journ. R. Anthrop. Institute.*

WEDNESDAY, SEPTEMBER 7.

The following Papers and Reports were read :—

1. *On Mourning Dress.* *By* E. SIDNEY HARTLAND.

The question of mourning dress was discussed by Professor Frazer in the fifteenth volume of the *Journal of the Anthropological Institute*, in which he raised several questions that have not yet been definitely settled. It is clear, as he says, that mourning garb was intended to be something quite distinctive from, if not the reverse of, ordinary costume, but its exact purpose seems still to be under discussion. It has been suggested that it was meant as a disguise in order to deceive the ghost of the dead. All kinds of spirits are easily deceived; but while it is clear that protection is required from the spirits of the dead, various examples make it by no means so clear that that protection took the form of disguise. Weapons and amulets are certainly employed. Other suggestions are that mourning garb and customs were intended as a return to more primitive conditions as a means of expressing the union with the dead. The mourner was supposed to partake, to some extent, of the condition of the dead, especially during the arduous journey of the ghost to its ultimate home. On the whole some weight must be given to these suggestions, but the real intention seems more likely to have been an expression of sorrow and abasement so as to deprecate the malice of a spirit which was naturally annoyed at finding itself disembodied.

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2. *Some Prehistoric Monuments in the Scilly Isles.* *By* H. D. ACLAND.

The present communication is the outcome of a study of the remains of the prehistoric monuments in the Scilly Isles during the past seven years. Although not yet complete, it is desirable that the results at present reached should be discussed in the hope that help in elucidating some of the problems presented may be obtained.

Two groups of menhirs were described, each of which appears to have an unusual arrangement. Several of the menhirs of one group have a constant orientation differing four degrees from the normal bearing.

A group of intersecting banks was also described. The bearings of the different members have the same variation from a normal bearing as the menhirs in one of the groups first described.

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3. *Excavation of Broch of Cogle, Watten, Caithness.* *By* ALEX. SUTHERLAND.

It is due to Dr. Anstruther Davidson, Los Angelos, that the existence of the Broch was proved. Dr. Davidson had seen the mounds of California, and on a visit to his birthplace in August 1905 he resolved to test the possibility of this Cogle mound containing anything of a bygone age. It stood about 6 feet high and 60 yards in diameter. He made a trial cut through the middle, and from this was satisfied there was here another of those prehistoric buildings called Brochs or Pict's houses, of which Mousa, in Bressay, Shetland, may be regarded as the best-preserved specimen.

Dr. Davidson now resolved to excavate and investigate, and communicated with Mr. John Nicolson Nybster, who had helped the late Sir Francis Tress Barry, M.P. for Windsor, in his explorations of similar structures at Keiss.

The plan was carefully drawn by exact measurements on the spot by Mr. Nicolson. The only entrance, about 2 feet wide, to the Cogle broch is on the west. At the Scottack and other excavated Caithness brochs the entrance is on the east.

The thickness of the walls is 15 feet, and the circle enclosed has a diameter

of 30 feet. There were two upright flagstones 2 feet high and 2 feet apart. The average height of the walls remaining *in situ* would be about 3 feet. Probably 60 or 70 feet had fallen and helped to form the mound. Vegetation had grown and decayed and buried the stupendous structure for ages. Who were the broch builders and when did they live? are interesting questions. Dr. Davidson identified five successive layers of ashes and pavement, and the charred remains of wood indicated the fuel. Trunks and branches of pine, birch, and hazel-nuts are frequently got in peat cutting at considerable depth in Cogle moss.

Dr. Davidson made sections of some of these pines, and found that their annual rate of growth coincided with that of the charred fragments found so abundantly in the broch.

The most important of the neolithic remains were the stone pestles found in the lowest stratum of ashes. These, over twenty, were in only a few instances pestle shaped. They were made of hard-grained, basaltic-like stone, and were originally of oval or oblong shape. By constant use in pounding the edges were bevelled, and a few of them were worn quite circular and bevelled all round. Two stones with shallow mortars were found. Some saddle querns were unearthed with the usual manu or hand-grinding stone. Numerous stone pebbles, probably used for sling stones, were found.

Almost all the bones were broken to extract the marrow. None showed evidence of fire, and the condition of the bones would show that they are very imperfectly cooked. Parts of tusks of boar, goat, horse, and ox could be identified, and also bat, with probably great auk. These have been sent to Professor Bryce, Glasgow University, for further investigation.

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4. *Some Unexplored Fields in British Archæology.* *By* George Clinch.

The purpose of this paper was threefold, viz. :—

1. To indicate some hitherto unexplored fields of research where antiquities await the spade of the field-archæologist;

2. To draw attention to the wholesale destruction of antiquities now going on in different parts of the kingdom; and

3. To suggest the establishment of regular and systematic oversight of great engineering works which involve excavation and removal of the soil.

The value of the spade in archæological investigations was never more appreciated than it is to-day; yet, in spite of activity in various directions, many fields of research remain either entirely unoccupied or only partially worked. Whilst Roman sites are being explored in considerable numbers in England, Wales, and Scotland, the remains of pre-Roman times are, with one or two exceptions, comparatively neglected. It is remarkable that so little attention is given to the sites of prehistoric huts and other dwellings. A hint of what may be expected by further excavation of these sites is afforded by the recent accidental discovery of gold torcs of the Bronze Age under the floors of ancient hut dwellings at Bexley, Kent.

The sites of ancient dwellings exist in large numbers in many parts of the country. They may be traced in much of the uncultivated land in England, as well as the mountainous districts of Wales. In certain districts in Wales dwelling-sites are particularly abundant, and in some cases in close proximity to bogs, a circumstance which suggests the advisability of draining the bogs with a view of recovering the antiquities which almost certainly are buried therein.

Other unoccupied archæological fields are blown-sands, dry river-beds, the dry sites resulting from shrunken and diverted rivers and drained marshes. In these various deposits the antiquities are in comparative safety, although in many districts scientific investigation, on the lines of the excellent work at Glastonbury, is most desirable.

The wholesale destruction of antiquities now going on as a result of coast-erosion, and railway and other great engineering works, is a most serious matter. There is pressing need for supervision of all these great works, in order that the antiquities may be rescued and the circumstances of their discovery placed on permanent record.

The writer advocated the immediate establishment, as far as possible, of a regular system of archæological oversight wherever and whenever excavations are being made in the soil; and he suggested that the matter be brought to the notice of the Government in order to enlist its sympathy and support.

5. *Report on the Lake Villages in the Neighbourhood of Glastonbury.* See Reports, p. 258.

6. *Report on the Age of Stone Circles.*—See Reports, p. 264.

7. *Report of the Anthropological Photographs Committee.* See Reports, p. 257.

8. *Report on the Preparation of a New Edition of Notes and Queries in Anthropology.*—See Reports, p. 266.

9. *Report on Archæological and Ethnological Investigations in Sardinia.*—See Reports, p. 264.

10. *Report on an Ethnographic Survey of Canada.*—See Reports, p. 265.

SECTION I.—PHYSIOLOGY.

PRESIDENT OF THE SECTION.—Professor A. B. MACALLUM, M.A., Ph.D., Sc.D., LL.D., F.R.S.

THURSDAY, SEPTEMBER 1.

The President delivered the following Address :—

THE record of investigation of the phenomena of the life of animal and vegetable cells for the last eighty years constitutes a body of knowledge which is of imposing magnitude and of surpassing interest to all who are concerned in the studies that bear on the organic world. The results won during that period will always constitute, as they do now, a worthy memorial of the intense enthusiasm of the scientific spirit which has been a distinguishing feature of the last six decades of the nineteenth century. We are to-day, in consequence of that activity, at a point of view the attainment of which could not have been predicted half a century ago.

This body of knowledge, this lore which we call cytology, is still with all this achievement in one respect an undeveloped science. It is chiefly—nay, almost wholly—concerned with the structural or morphological side of the cell, while of the functional phenomena our knowledge is only of the most general kind, and the reason is not far to seek. What little we know of the physiological side of the cell—as, for example, of cellular secretion, absorption, and nutrition—has only to a very limited extent been the outcome of observations directed to that end. It is in very great part the result of all the inferences and generalisations drawn from the data of morphological research. This knowledge is not the less valuable or the less certain because it has been so won, but simply because of its source and of the method by which we have gained it, it is of a fragmentary character, and therefore less satisfactory in our estimation.

This state of our knowledge has affected—or, to express it more explicitly, has fashioned—our concept of living matter. When we think of the cell it is idealised as a morphological element only. The functional aspect is not ignored, but we know very little about it, and we veil our ignorance by classing its manifestations as vital phenomena.

It is true that in the last twenty years, and more particularly in the last ten, we have gathered something from biochemical research. We know much concerning ferment or catalytic action, of the physical characters of colloids, of the constitution of proteins, and their synthesis in the laboratory promises to be an achievement of the near future. We are also in a position to understand a little more clearly what happens in proteins when, on decomposition in the cell, they yield the waste products, urea, and other metabolites, with carbon dioxide and water. Further, fats can be formed in the laboratory from glycerine and fatty acids, a large number of which have also been synthesised, and a very large majority of the sugars of the aldohexose type have been built up from simpler compounds. These facts indicate that some of the results of the activity of animal and vegetable cells may be paralleled in the laboratory, but that is as far as the resemblance extends. The methods of the laboratory are not as yet those of nature. In the formation of carbohydrates, for example, the chlorophyll-holding cell makes use of processes of the most speedy and effective character,

but nothing of these is known to us except that they are quite unlike the processes the laboratory employs in the artificial synthesis of carbohydrates. Nature works unerringly, unfalteringly, with an amazing economy of material and energy, while 'our laboratory syntheses are but roundabout ways to the waste sink.'

In consequence, it is customary to regard living matter as unique—*sui generis*, as it were without an analogue or parallel in the inorganic world—and the secrets involved in its actions and activities as insoluble enigmas. Impelled by this view there are those, also, who postulate as an explanation for all these manifestations the intervention in so-called living matter of a force otherwise and elsewhere unknown, biotic or vital, whose action is directed, according to the character of the structure through which it operates, to the production of the phenomena in question. Living protoplasm is, in this view, but a mask and a medium for action of the unknown force.

This is an old doctrine, but it has again made headway in recent years owing to the reaction from the enthusiasm which came from the belief that the application of the known laws of physics and chemistry in the study of living matter would explain all its mysteries. A quarter of a century ago hopes were high that the solution of these problems would soon be found in a more profound comprehension of the laws of the physical world. Since then there has been an extraordinary increase in our knowledge of the structure and of the products of the activity of living matter without a corresponding increase in knowledge of the processes involved. The obscurity still involving the latter appears all the greater because of the high lights thrown on the former. Despair, in consequence, has taken the place of hope with some, and the action of a mysterious force is invoked to explain a mystery.

It may be admitted that our methods of investigation are very inadequate, and that our knowledge of the laws of matter, seemingly comprehensive, is not at present profound enough to enable us to solve all the problems involved in the vital phenomena. The greatest factor in the difficulty of their solution, however, has been the fact that there has been a great lack of investigators specially trained not only in biology, but also in physics and chemistry, for the very purpose of attacking intelligently such problems. The biologists, for want of such a wide training, have emphasised the morphological aspect and the readily observable phenomena of living matter; while the physicist and chemist, knowing little of the morphology of the cell and of its vital manifestations, have been unable to apply satisfactorily the principles of their sciences to an understanding of its processes. The high degree of specialism which certain departments of biology have in recent years developed has made that difficulty greater than it was.

It must also be said that in some instances in which the physicist and chemist attempted to aid in the solution of biological problems the result on the whole has not been quite satisfactory. In, for example, the phenomena of osmosis the application of Arrhenius' theory of ionisation and van't Hoff's gas theory of solutions promised at first to explain all the processes and the results of diffusion through animal membranes. These theories were supported by such an array of facts from the side of physics and physical chemistry that there appeared to be no question whatever regarding their universal validity, and their application in the study of biological phenomena was urged with acclaim by physical chemists and eagerly welcomed by physiologists. The result in all cases was not what was expected. Diffusion of solutes, according to the theories, should, if the membrane is permeable to them, always be from the fluid where their concentration is high to that in which it is low. This appears to happen in a number of instances in the case of living membrane—or, at least, we may assume that it occurs—but in one signal instance at least the very reverse normally obtains. In the kidney, membranes formed of cells constituting the lining of the glomeruli and the renal tubules separate the urine, as it is being formed, from the blood plasma and the lymph circulating through the kidney. Though the excreted fluid is derived from the plasma and lymph, it is usually of much greater osmotic concentration than the latter.

It may be urged that this and other discrepancies are explained by the distribution (or partition) coefficient of the solutes responsible for the greater

concentration of the product of excretion, these solutes being more soluble in the excreted medium than in the blood plasma, and distributing or diffusing themselves accordingly. If such a principle is applicable here as an explanation, it may be quite as much so in other physiological cases in which the results are supposedly due only to the forces postulated in the theories of van't Hoff and Arrhenius. Whether this be so or not, the central fact remains that the enthusiastic hopes with which the theories were applied by physiologists and biologists in the explanation of certain vital phenomena have not been wholly realised.

The result has been a reaction amongst physiologists and biologists which has not been the least contributory of all the causes that have led to the present revival of vitalism.

Another difficulty in accounting for the vital phenomena has been due, until recently, to a lack of knowledge of the physical and chemical properties of colloids and colloidal 'solutions.' The importance of this knowledge consists in the fact that protoplasm, 'the physical basis' of life, consists mainly of colloids and water. Till eleven years ago what was known regarding colloids was derived chiefly from the researches of Graham (1851-62), Ljubavin (1889), Barus and Schneider (1891), and Linder and Picton (1892-97), who were the pioneers in this line. In 1899 were published the observations of Hardy, through whose investigations very great progress in our knowledge of colloids was made. In 1903 came the invention of the ultramicroscope by Siedentopf and Zsigmondy, by which the suspension character of colloid material in its so-called 'solutions' was visually demonstrated. During the last seven years a host of workers have by their investigations greatly extended our knowledge of the physical and chemical properties of colloids, and now the science of Collochemistry bids fair, the more it develops, to play a very important part in all studies bearing on the constitution and properties of living matter.

Then, also, there are the phenomena of surface tension. This force, the nature of which was first indicated by Segner in 1751, and described with more detail by Young in 1804 and La Place in 1806 in the expositions of their theories of capillarity, was first in 1869 only casually suggested as a factor in vital processes by Engelmann. Since the latter date and until 1892, when Bütschli published his observations on protoplasmic movement, no serious effort was made to utilise the principle of this force in the explanation of vital phenomena. Even to-day, when we know more of the laws of surface tension, it is only introduced as an incidental factor in speculations regarding the origin of protoplasmic movement and muscular contraction, and yet it is, as I shall maintain later on in this address, the most powerful, the most important of all the forces concerned in the life of animal and vegetable cells.

It may be gathered from all that I have advanced here that the chief defect in biological research has been, and is, the failure to apply thoroughly the laws of the physical world in the explanation of vital phenomena. Because of this too much emphasis is placed on the division that is made between the biological and the physical sciences. This division is very largely an artificial one, and it will in all probability be maintained eventually only as a convenience in the classification of the sciences. The biologist and physiologist have to deal with problems in which a wide range of knowledge is necessary for their adequate treatment; and, if the individual investigator has not a very extensive training in the physical sciences, it is impossible for him to have at his command all the facts bearing on the subject of his research, unless the problem involved be a very narrow one. The lack of this wide knowledge of the physical sciences tends to specialism, and, as the specialism is ever growing, it will produce a serious situation eventually, for it will develop a condition in the scientific world in which co-ordination of effort and a broad outlook will be much more difficult than is the case now.

This growing defect in the biological sciences can only be lessened by the insistence of those in charge of advanced courses in biological and physiological laboratories that only they whose training is of a very wide character should be allowed to take up research. It is, perhaps, futile to expect that such a rule will ever be enforced, for in the keen competition between universities for young teachers who have made some reputation for original investigation there may not be too close a scrutiny of the qualifications of those who offer themselves for post-graduate courses. There is, further, the difficulty that the heads of scientific

departments are not desirous of limiting the output of new knowledge from their laboratories by insisting on the wider training for the men of science who are in the process of developing as students of research.

It is perhaps true, also, that there still remains a great deal unobserved or unrecorded in the fields of biology, physiology, and biochemistry, in the investigation of all of which a broad training is not specially required to give good service; and that, further, this condition will obtain for one or two decades still. It is quite as certain, however, that the returns from such service will tend to diminish in number and value, and, if the coming generation of workers is not recruited from a systematically and broadly trained class of students, a period of comparative sterility may supervene.

As it is to-day, there are few who devote themselves to the direct study of the chemical and physical properties of the cell, the fundamental unit of living matter. There are, of course, many who are concerned with the morphology of the cell, and who employ in their studies the methods of hardening and staining which have been of very great service in revealing the structural as well as the superficial chemical properties of the cell. On the facts so gained views are based which deal with the chemistry of the cell, and which are more or less widely accepted, but the results and generalisations drawn from them give us but little insight into the chemical constitution of the cell. We recognise in the morphologists' chromatin a substance which has only in a most general way an individuality, while the inclusions in the nucleus and the cytoplasm, on whose distinction by staining great emphasis is laid, can only in a most superficial way be classified chemically.

The results of digestion experiments on the cell structures are also open to objection. The action of pepsin and hydrochloric acid must depend very largely on the accessibility of the material whose character is to be determined. If there are membranes protecting cellular elements, pepsin, which is a colloid, if it diffuses at all, must in some cases at least penetrate them with difficulty. In *Spirogyra*, for example, the external membrane formed of a thick layer of cellulose is impermeable to pepsin, but not to the acid; and, in consequence, the changes which occur in it during peptic digestion are due to the acid alone. Even in the cell whose periphery is not protected by a membrane, the insoluble colloid material at the surface serves as a barrier to the free entrance of the pepsin. It is, however, more particularly in the action on the nucleus and its contents that peptic digestion fails to give results which can be regarded as free from objection. Here is a membrane which during life serves to keep out of the nucleus not only all inorganic salts but also all organic compounds, except chiefly those of the class of nucleo-proteins. That such a membrane may, when the organism is dead, be permeable to pepsin is at least open to question, and in consequence what we see in the nucleus after the cell has been acted on by pepsin and hydrochloric acid cannot be adduced as evidence of its chemical or even of its morphological character.

The results of digestive experiments on cells are, therefore, misleading. What may from them appear as nucleo-protein may be anything but that, while, if the pepsin penetrates as readily as the acid, there should be left not nucleo-protein, but pure nucleic acid, which should not stain at all.

The objections which I now urge against the conclusions drawn from the results of digestion experiments have developed out of my own observations on yeast cells, diatoms, *Spirogyra*, and especially the Blue-green Algæ. The latter are, as is *Spirogyra*, encased in a membrane which is an effective barrier to all colloids. When, therefore, threads of *Oscillaria* are subjected to the action of artificial gastric juice, a certain diminution in volume is observed owing to the dissolving power of the hydrochloric acid, and an alteration of the staining power of certain structures is found to obtain; but the pepsin has nothing to do with these, as may be determined by examination of control preparations treated with a solution of hydrochloric acid alone.

It is thus seen how slender is our knowledge of the chemistry of cells derived from staining methods and from digestion experiments. That, however, has not been the worst result of our confidence in our methods. It has led cytologists to rely on these methods alone, to leave undeveloped others which might have thrown great light on the chemical constitution of the cell, and which might have

enabled us to understand a little more clearly the causation of some of the vital phenomena.

It was the futility of some of the old methods that led me, twenty years ago, to attack the chemistry of the cell from what appeared to me a correctly chemical standpoint. It seemed to me then, and it appears as true now, that a diligent search for decisive chemical reactions would yield results of the very greatest importance. In the interval I have been able to accomplish only a small fraction of what I hoped to do, but I think the results have justified the view that, if there had been many investigators in this line instead of only a very few, the science of Cytochemistry would play a larger part in the solution of the problems of cell physiology than it now does.

The methods and the results are, as I have said, meagre, but they show distinctly indeed that the inorganic salts are not diffused uniformly throughout the cell; that in vegetable cells they are rigidly localised, while in animal cells, except those devoted to absorption and excretion, they are confined to specified areas in the cell. Their localisation, except in the case of inorganic salts of iron, is not due to the formation of precipitates, but rather to a condition which is the result of the action of surface tension. This seems to me to be the only explanation for the remarkable distribution, for example, of potash salts in vegetable cells. We know that, except in the chloroplatinate of potassium and in the hexanitrite of potassium, sodium and cobalt, potassium salts form no precipitates; and yet, in the cytoplasm of vegetable cells, the potassium is so localised at a few points as to appear at first as if it were in the form of a precipitate. In normal active cells of *Spirogyra* it is massed along the edge of the chromotophor, while in the mesophyllic cells of leaves it is condensed in masses of the cytoplasm, which are by no means conspicuous in ordinary preparations of these cells.

This effect of surface tension in localising the distribution of inorganic salts at points in the cytoplasm would explain the distribution of potassium in motor structures. In striated muscle the element is abundant in amount, and is confined to the dim bands in the normal conditions. In *Vorticella*, apart from a minute quantity present at a point in the cytoplasm, it is found in very noticeable amounts in the contractile stalk; while in the Holotrichate Infusoria (*Paramœcium*) it is in very intimate association with the basal elements of the cilia in the ectosarc. This, indeed, would seem to indicate that the distribution of the potassium is closely associated with contraction, and, therefore, with the production of energy in contractile tissues. The condensation of potassium at a point may, of course, be a result of a combination with portions of the cytoplasm, but we have no knowledge of the occurrence of such compounds; and, further, the presence of such does not explain anything, or account for the liberation of energy in motor contraction. On the other hand, the action of surface tension would explain not only the localisation of the potassium but also the liberation of the energy.

In vessels holding fluids the latter, in relation to surface tension, have two surfaces—one free, in contact with the air, and known as the air-water surface; the other, that in contact with the wall of the containing vessel (glass). In the latter the tension is lower than in the former. When an inorganic compound—a salt, for example—is dissolved in the fluid it increases the tension at the air-water surface, but its dilution is much greater here than in any other part of the fluid; while at the other surface its concentration is greatest. In the latter case the condition is of the nature of adsorption. The condensation on that portion of the surface where the tension is least is responsible for what we find when a solution of a coloured salt, as, *e.g.*, potassium permanganate, is driven through a layer of dry sand. If the latter is of some considerable thickness the fluid as it passes out is colourless. The air-solution surface tension is higher than the tension of each of the solution-sand surfaces on which, therefore, the permanganate condenses or is adsorbed. The same phenomenon is observed when a long strip of filter-paper is allowed to hang with its lower end in contact with a moderately dilute solution of a copper salt. The solution is imbibed by the filter-paper, and it ascends a certain distance in a couple of minutes, when it may be found that the uppermost portion of the moist area is free from even a trace of copper salt.

If, on the other hand, an organic compound—as, for instance, one of the bile salts—instead of an inorganic compound is dissolved in the fluid, the surface tension of the air-water surface is reduced, and in consequence the bile salt is concentrated at that surface; while in the remainder of the fluid, and particularly in that portion of it in contact with the wall of the vessel, the concentration is reduced.

The distribution of a salt in such a fluid, whether it lowers surface tension or increases it, is due to the action of a law which may be expressed in words to the effect that the concentration in a system is so adjusted as to reduce the energy at any point to a minimum.

Our knowledge of this action of inorganic and organic substances on the surface tension in a fluid and of the differences in their concentrations throughout the latter was contained in the results of the observations on gas mixtures by J. Willard Gibbs, published in 1878. The principle as applied to solutions was independently discovered by J. J. Thomson in 1887. It is known as the Gibbs' principle, although the current enunciations of it contain the more extended observations of Thomson. As formulated usually it is more briefly given, and its essential points may be rendered in the statement *that when a substance on solution in a fluid lowers the surface tension of the latter the concentration of the solute is greater in the surface layer than elsewhere in the solution; but when the substance dissolved raises the surface tension of the fluid, the concentration of the solute is least in the surface layers of the solution.*

It is thus seen how in a system like that of a drop of water with different contact surfaces the surface tension is affected, and how this alters the distribution of solutes. It is further to be noted that for most organic solutes the action in this respect is the very reverse of that of inorganic salts. Consequently, in a living cell which contains both inorganic and organic solutes, and in which there are portions of different composition and density, the equilibrium may be subject to disturbance constantly through an alteration of the surface tension at any point. Such a disturbance may be found in a drop of an emulsion of olive oil and potassium carbonate in the well-known experiments of Bütschli. When the emulsion is appropriately prepared, a minute drop of it, after it is surrounded with water, will creep under the cover glass in an amœboid fashion for hours, and the movement will be more marked and rapid when the temperature is raised to 40° to 50° C. All the phenomena manifested are due to a lowering of the surface tension at a point on the surface, as a result of which there is protrusion there of the contents of the drop, accompanied, Bütschli holds, by streaming cyclic currents in the remainder of the mass.

Surface tension also, according to J. Traube, is all-important in osmosis, and he holds that it is the solution pressure (*Haftdruck*) of a substance which determines the velocity of the osmotic movement and the direction and force of the osmotic pressure. The solution pressure of a substance is measured by the effect that substance exercises when dissolved on the surface tension of its solution, or, to put it in Traube's own way, the more a substance lowers or raises the surface tension of a solvent (water) the less or greater is the solution pressure (*Haftdruck*) of that substance. This solution pressure, Traube further holds, is the only force controlling osmosis through a membrane, and he rejects completely the bombardment effect on the septum postulated in the van't Hoff theory of osmosis.

The question as to the nature of the factors concerned in osmosis must remain undecided until the facts have been more fully studied from the physiological standpoint, but enough is now known to indicate that surface tension plays at least a part in it, and the omission of all consideration of it as a factor is not by any means a negligible defect in the van't Hoff theory of osmosis.

The occurrence of variations in surface tension in the individual cells of an organ or tissue is difficult to demonstrate directly. We have no methods for that purpose, and, in consequence, one must depend on indirect ways to reveal whether such variations exist. The most effective of these is to determine the distribution of organic solutes and of inorganic salts in the cell. The demonstration of the former is at present difficult, or even in some cases impossible. The occurrence of soaps which are amongst the most effective agents in lowering surface tension may be revealed without difficulty microchemically, as may also neutral fats;

but we have as yet no delicate microchemical tests for sugars, urea, and other nitrogenous metabolites, and in consequence the part they play, if any, in altering the surface tension in different kinds of cells, is unknown. Further research may, however, result in discovering methods of revealing their occurrence microchemically in the cell. We are in a like difficulty with regard to sodium, whose distribution we can determine microchemically in its chief compounds, the chloride and phosphate, only after the exclusion of potassium, calcium, and magnesium. We have, on the other hand, very sensitive reactions for potassium, iron, calcium, haloid chlorine, and phosphoric acid, and with methods based on these reactions it is possible to localise the majority of the inorganic elements which occur in the living cell.

By the use of these methods we can indirectly determine the occurrence of differences in surface tension in a cell. This determination is based on the deduction from the Gibbs-Thomson principle that, where in a cell an inorganic element or compound is concentrated, the surface tension at the point is lower than it is elsewhere in the cell. If, for example, it is concentrated on one wall of a cell. The thickness of this layer must vary with the osmotic concentration in the cell, with the specific composition of the colloid material of the cytoplasm and with the activity of the cell, but it should not exceed a few hundredths of a millimetre (0·02 to 0·04 mm.), while it might be very much less in an animal cell whose greatest diameter does not exceed 20 μ.

Numerous examples of such localisation may be observed in the confervoid Protophyta. In *Ulothrix*, ordinarily, there is usually a remarkable condensation of the potassium at the ends of the cell on each transverse wall. The surface tension, on the basis of the deduction from the Gibbs-Thomson principle, should be, in all these cases, high on the lateral walls and low on those surfaces adjoining the transverse septa.

The use of this deduction may be extended. There are in cells various inclusions whose composition gives them a different surface tension from that prevailing in the external limiting area of the cell. Further, the limiting portion of the cytoplasm in contact with these inclusions must have surface tension also. When, therefore, we find by microchemical means that a condensation of an inorganic element or compound obtains immediately within or without an inclusion, we may conclude that there, as compared with the external surface of the cell, the surface tension is low. It may be urged that the condensation is due to absorption only, but this objection cannot hold, for in the Gibbs-Thomson phenomena the localisation of the solute at a part of the surface as the result of high tension elsewhere of the solution is, in all probability, due to absorption, and is indeed so regarded.[1]

It is in this way that we can explain the remarkable localisation of potassium in the cytoplasm at the margins of the chromatophor in *Spirogyra* and also the extraordinary quantities of potassium held in or on the inclusions in the mesophyllic cells of leaves. In Infusoria (*Vorticella*, *Paramoecium*) the potassium present apart from that in the stalk or ectosarc is confined to one or more small granules or masses in the cytoplasm.

How important a factor this is in clearing the active portion of the cytoplasm of compounds which might hamper its action, a little consideration will show. In plants very large quantities of salts are carried to the leaves by the sap from the roots, and among these salts those of potassium are the most abundant as a rule. Reaching the leaves these salts do not return, and in consequence during the functional life of the leaves they accumulate in the mesophyllic cells in very large quantities, which, if they were not localised as described in the cell, would affect the whole cytoplasm and alter its action.

Enough has been advanced here to indicate that surface tension is not a minor feature in cell life. I would go even further than this and venture to say that the energy evolved in muscular contraction, that also involved in secretion and excretion, the force concerned in the phenomena of nuclear and cell division, and that force also engaged by the nerve cell in the production of a nerve impulse are but manifestations of surface tension. On this view the living cell is but a machine, an engine, for transforming potential into kinetic and other forms of energy, through or by changes in its surface energy.

[1] See Freundlich, *Kapillarchemie*, p. 50, 1909.

To present an ample defence of all the parts of the thesis just advanced is more than I propose to do in this address. That would take more time than is customarily allowed on such an occasion, and I have, in consequence, decided to confine my observations to outlines of the points as specified.

It is not a new view that surface tension is the source of the muscular contraction. As already stated, the first to apply the explanation of this force as a factor in cellular movement was Engelmann in 1869, who advanced the view that those changes in shape of cells which are classed as contractile are all due to that force which is concerned in the rounding of a drop of fluid. The same view was expressed by Rindfleisch in 1880, and by Berthold in 1886, who explained the protoplasmic streaming in cells as arising in local changes of surface tension between the fluid plasma and the cell sap, but he held that the movement and streaming of *Amœbæ* and *Plasmodiæ* are not to be referred to the same causes as operate in the protoplasmic streaming in plant cells. Quincke in 1888 applied the principle of surface tension in explaining all protoplasmic movement. In his view the force operates, as in the distribution of a drop of oil on water, in spreading protoplasm, which contains oils and soaps, over surfaces in which the tension is greater, and as soap is constantly being formed, the layer containing it, having a low tension on the surface in contact with water, will as constantly keep moving, and as a result pull the protoplasm with it. The movement of the latter thus generated will be continuous and constitute protoplasmic streaming. In a similar way Bütschli explains the movement of a drop of soap emulsion, the layer of soap at a point on the surface of the spherule dissolving in the water and causing there a low tension and a streaming of the water from that point over the surface of the drop. This produces a corresponding movement in the drop at its periphery and a return central or axial stream directed to the point on the surface where the solution of the soap occurred, and where now a protrusion of the mass takes place resembling a pseudopodium. In this manner, Bütschli holds, the contractile movements of *Amœbæ* are brought about. In these the chylema or fluid of the foam-like structure in the protoplasm is alkaline, it contains fatty acids, and, in consequence, soaps are present which, through rupture of the superficial vesicles of the foam-like structure at a point, are discharged on the free surface and produce there the diminution of surface tension that calls forth currents, internal and external, like those which occur in the case of the drop of oil emulsion.

The first to suggest that surface tension is a factor in muscular contraction was D'Arsonval, but it was Imbert who, in 1897, directly applied the principle in explanation of the contractility of smooth and striated muscle fibre. In his view the primary conditions are different in the former from what obtain in the latter. In smooth muscle fibre the extension is determined, not by any force inside it, but by external force such as may distend the organ (intestine, bladder, and arteries) in whose wall it is found. The 'stimulus' which causes the contraction increases the surface tension between the surface of the fibre and the surrounding fluid, and this of itself has the effect of making the fibre tend to become more spherical or shorter and thicker, which change in shape does occur during contraction. He did not, however, explain how the excitation altered the surface tension, except to say that its effect on surface tension is like that of electricity, with which the nerve impulse presents some analogy. In striated fibre, on the other hand, the discs constituting the light and dim bands have each a longitudinal diameter which is an effect of its surface tension, and this causes extension of the fibre during rest. When a nerve impulse reaches the fibre the surface tension of the discs is altered, and there results a deformation of each, involving a shortening of its longitudinal axis and thus a shortening of the whole fibre.

According to Bernstein, in both smooth and striated muscle fibre there is, in addition to surface tension, an elastic force residing in the material composing the fibre which, according to the conditions, sometimes opposes and sometimes assists the surface tension. The result is that in the muscle fibre at rest the surface must exceed somewhat that of the fibre in contraction. In both conditions the sum of the two forces, surface tension and elasticity, must be zero. In contraction the surface tension increases, and with it the elasticity also. Taken as a whole this would not explain the large force generated in contraction, for the energy liberated would be the product of the surface tension and the amount representing

the diminution of the surface due to the contraction. As the latter is very small the product is much below the amount of energy in the form of work done actually manifested. To get over this difficulty Bernstein postulates that in muscle fibres, whether smooth or striated, there are fibrils surrounded by sarcoplasma, and that each fibril is formed of a number of cylinders or biaxial ellipsoids singly disposed in the course of the fibril, but separated from each other by elastic material and surrounded by sarcoplasma. Between the ellipsoids and the sarcoplasma there is considerable surface tension, which prevents mixture of the substances constituting both. The excitation through the nerve impulse causes an increase of surface tension in these ellipsoids, and they become more spherical. In consequence the decrease in surface of all the ellipsoids constituting a fibril is much greater than if the fibril were to be affected as an individual unit only by an increase of surface tension, and thus the surface energy developed would be correspondingly greater. The ellipsoids, Bernstein explains, are not to be confused with the discs, singly and doubly refractive in striated fibre; for these, he holds, are not concerned in the generation of the contraction but with the processes that make for rapidity of contraction. The extension of a muscle after contraction is due to the elastic reaction of the substance between the ellipsoids in the fibrils. Bernstein further holds that fibrils of this character occur in the protoplasm of *Amœbæ*, in the stalk of *Vorticella*, and in the ectoplasma of *Stentor*, and this explains their contractility.

It may be said in criticism of Bernstein's view that his ellipsoids are from their very nature non-demonstrable structures, and, therefore, must always remain as postulated elements only. Further, it may be pointed out that he attributes too small a part to surface tension in the lengthening of the fibre after contraction, and that the elasticity which muscle appears to possess is, in the last analysis, but a result of its surface tension.

As regards Quincke's explanation of protoplasmic movement and streaming, as well as of muscular contraction, Bütschli has shown that it is based on a mistaken view of the structure of the cell in *Chara* and other plant forms in which protoplasmic streaming occurs. Bütschli's own hypothesis, however, is defective in that it postulates a current in the fluid medium just outside the *Amœba* and backward over its surface, the existence of which Berthold denies, and Bütschli himself has been unable to demonstrate, even with the aid of fine carmine powder in the fluid. He did, indeed, observe a streaming in the water about a creeping *Pelomyxa*, but the current was in the opposite direction to that demanded by his hypothesis. Further, his failure to demonstrate the occurrence of the postulated backflow in the water about the contracting or moving mass of an *Amœba* or a *Pelomyxa*, makes it difficult to accept the hypothesis he advanced to explain that backflow, namely, that rupture of peripheral vesicles (*Waben*) of the protoplasm occurs, with a consequent discharge of their contents (proteins, oils, and soaps) into the surrounding fluid. Surface tension, further, on this hypothesis would be an uncertain and wasteful factor in the life of the cell. On *a priori* grounds also it would seem improbable that this force should be generated outside instead of inside the cell.

One common defect of all these views is that they made only a limited application of the principle of surface tension. This was because some of its phenomena were unknown, and especially those illustrating the Gibbs-Thomson principle. With its aid and with the knowledge of the distribution of inorganic constituents in animal and vegetable cells that microchemistry gives us we can make a more extended application of surface tension as a factor in cellular life than was possible ten years ago.

In regard to muscle fibre this is particularly true, and microchemistry has been of considerable service here. From the analyses of the inorganic constituents of striated muscle in vertebrates made by J. Katz and others we know that potassium is extraordinarily abundant therein, ranging from three and a half in the dog to more than fourteen times in the pike the amount of sodium present. How the potassium salt is distributed in the fibre was unknown before 1904, in which year, by the use of a method, which I had discovered, of demonstrating the potassium microchemically, the element was found localised in the dim bands. Later and more extended observations suggested that in the dim band itself, when the muscle fibre is at rest, the potassium is not uniformly

distributed, and it was found to be the case in the wing muscles of certain of the insecta—as, for example, the scavenger beetles—in which the bands are broad and conspicuous enough to permit ready observation on this score. In these the potassium salt was found to be localised in the zones of each dim band adjacent to each light band. Subsequently Miss M. L. Menten, working in my laboratory and using the same microchemical method, found the potassium similarly limited in its distribution in the muscle fibres of a number of other insects. She determined, also, that the chlorides and phosphates have a like distribution in these structures, and it is consequently probable that sodium, calcium, and magnesium have the same localisation.

Macdonald has also made investigations on the distribution of potassium in the muscle fibre of the frog, crab, and lobster, using for this purpose the hexanitrite reagent. He holds, as a result of his observations, that the element in the uncontracted fibril is limited to the sarcoplasm in the immediate neighbourhood of the singly refractive substance, while it is abundantly present in the central portion of each sarcomere of the contracted fibril—that is, in the doubly refractive material. I am not inclined to question the former point, as I have not investigated the microchemistry of the muscle in the crab and lobster, and my only criticism would be directed against placing too great reliance on the results obtained in the case of frog's muscle. The latter is only very slowly penetrated by the hexanitrite reagent, and, apparently because of this, alterations in the distribution of the salts occur and, as I have observed, the potassium may be limited to the dim bands of one part of the contracted fibre and may be found in the light bands of another part of the same. In the wing muscles of insects in the uncontracted condition such disconcerting results are not so readily obtained, owing, it would seem, to the readiness with which the fibrils may be isolated and the almost immediate penetration of them by the reagent. Here there is no doubt about the occurrence of the element in the zones of the dim band immediately adjacent to the light bands.

Whether the potassium in the resting fibre is in the sarcoplasm or in the sarcostyle I would hesitate to say. It may be as Macdonald claims, but I find it difficult to apply in microchemical studies of muscle fibre the concepts of its more minute structure gained from merely stained preparations. Because of this difficulty I have refrained from using here, as localising designations, other expressions than 'light bands' and 'dim bands.' The latter undoubtedly include some sarcoplasm, but in the case of the resting fibre I am certain only of the presence of potassium, as described, in the dim band regarded as an individual part, and not as a composite structure.

Now, on applying the Gibbs-Thomson principle enunciated above, this distribution would seem to indicate that in the dim band of a fibril the surface tension is greatest on its lateral walls, in consequence of which the potassium salts are concentrated in the vicinity of the remaining surfaces, *i.e.*, those limiting the light bands. This explanation would seem to be confirmed by the observations I made on the contracted fibrils of the wing muscles of a scavenger beetle. In these the potassium was found uniformly distributed throughout each dim band, which, instead of being cylindrical in shape as in the resting element, is provided with a convexly curved lateral wall, and therefore with a smaller surface than the mass of the dim band has when at rest. This contour suggests that the surface tension on the lateral wall is lessened to an amount below that of either terminal surface, followed by a redistribution of the potassium salt to restore the equilibrium thus disturbed. The consequent shortening of the dim bands of the fibrils would account for the contraction of the muscle.

How the surface tension of the lateral wall of the dim band is lessened in contraction is a question which can only be answered after much more is known of the nature of the nerve impulse as it reaches the muscle fibril, and of the part played by the energy set free in the combustion process in the dim bands. It may be that electrical polarisation, as a result of the arrival of the nerve impulse, develops on the surface of the lateral wall, and as a consequence of which its surface tension is diminished. The energy so lost appears as work, and it is replaced by energy, one may suppose, derived from the combustion of the material in the dim band. In this case the disturbance of surface tension would be primary, while the combustion process would be secondary, in the order of

time. In support of this explanation may be cited the fact that the current of action in muscle precedes in time the contraction itself—that is, the electrical response of the stimulus occurs in the latent period and immediately before the contraction begins.

It may, however, be postulated, on the other hand, that the chemical changes occur in those parts of the dim band immediately adjacent to the light bands, and as a result the tension of the terminal surfaces may be increased, this resulting in the shortening of the longitudinal axis of the dim band and the displacement laterally of the contents. This would imply that the energy of muscle contraction comes primarily from that set free in the combustion process, and not indirectly as involved in the former explanation.

Whatever may be the cause of the alteration in surface tension, there would seem to be no question of the latter. The very alteration in shape of the dim band in contraction makes it imperative to believe that surface tension is concerned. The redistribution of the potassium which takes place as described in the contracting fibrils of the wing muscles of the scavenger beetle can be explained in no other way than through the alteration of surface tension.

In the smooth muscle fibre potassium is also present and in close association throughout with the membrane. When a fresh preparation of smooth muscle is treated so as to demonstrate the presence of potassium, the latter is shown in the form of a granular precipitate of hexanitrite of sodium, potassium, and cobalt in the cement substance between the membranes of the fibres. In the smooth muscle fibres in the walls of the arteries in the frog the precipitate in the cement material is abundant, and its disposition suggests that it plays some part in the *rôle* of contraction. Inside of the membrane potassium occurs, but in very minute quantities, which, with the cobalt sulphide method, gives a just perceptible dark shade to the cytoplasm as a whole. Microchemical tests for the chlorides and phosphates indicate that the cytoplasm is almost wholly free from them, and consequently there is very little inorganic material inside of the fibre. Chlorides and phosphates, but more particularly the former, are abundant in the cement material, and their localisation here would seem to indicate that the potassium of the same distribution is combined chiefly as chloride.

In smooth muscle fibre, then, the potassium is distributed very differently from what it is in striated fibre, and on first thought it seemed difficult to postulate that the contraction could be due to alterations of surface tension. This, however, would appear to be the most feasible explanation, for the potassium salts in the cement substance might be supposed to shift their position under the influence of electrical force so as to reach the interior of the membranes of the fibres, in which case the surface tension of the latter would be immediately increased and the fibre itself would in consequence at once begin to contract. The slowness with which this shifting into, or absorption by, the membrane of the potassium salts would take place would also account for the long latent period of contraction in smooth muscle.

It is of interest here to note that the potassium ions have the highest ionic mobility (transport number) of all the elements of the kationic class, except hydrogen, which are found to occur in connection with living matter. Its value in this respect is half again as great as that of sodium, one-eighth greater than that of calcium, and one-seventh greater than that of magnesium. This high migration velocity of potassium ions would make the element of special service in rapid changes of surface tension.

Loew has pointed out that potassium in the condensation processes of the synthesis of organic compounds has a catalytic value different from that of sodium. For example, ethyl aldehyde is condensed with potassium salts to aldol, with sodium salts to crotonic aldehyde (Kopf and Michael). Potassium is, but sodium is not, effective in the condensation of carbon monoxide. When phenol is fused with potassium salts condensation products like diphenol are produced, but when sodium salts are used the products are dioxybenzol and phlorogluein (Barth). It is, therefore, not improbable that potassium, along with those properties which come from its ionic mobility, has a special value in the metabolism of the dim bands of striated muscle fibre and in the condensation synthesis which characterise the chromatophors of Protophyta (*Spirogyra*, *Zygnema*).

With the use of this method of determining differences in surface tension in cells it is possible, in some cases at least, to ascertain whether this force plays a part in both secretion and excretion, and evidence in favour of this view can be found in the pancreatic cells of the rabbit, guinea pig, and in the renal cells of the frog. In the pancreatic cells there is an extraordinary condensation of potassium salts in the cytoplasm of each cell adjacent to the lumen of the tubule, and during all the phases of activity—except, it would appear, that of the so-called "resting stage"—potassium salts occur in, and are wholly confined to, this part of each cell. It is difficult to say whether they pass into the lumen with the secretion and their place taken by more from the blood-stream and lymph, but the important point is that the condensation of potassium salts immediately adjacent to the lumen seems to indicate a lessened surface tension on the lumen surface of the cell.

According to Stoklasa[1] the pancreas of the pig is much richer in potassium than in sodium, the dried material containing 2·09 per cent. of potassium and 0·28 per cent. of sodium, while the values for the dried material of ox muscle are, as he determined them, 1·82 and 0·26 per cent. respectively. It is significant that in the pancreas this large amount of potassium should be localised as described.

In the renal cells of vertebrates there is usually a considerable amount of potassium salts distributed throughout the cytoplasm. These cells are always active in the elimination of the element from the blood, and it is in consequence not possible to determine whether there are differences in surface tension in them. Under certain conditions, however, these can be demonstrated. In the frogs which have been kept in the laboratory tanks throughout the winter, and in the blood of which the inorganic salts have been, because of the long period of inanition, reduced to almost hyptonic proportions, the renal cells are very largely free from potassium. When it is present it is usually diffused throughout the cytoplasm. If now a few cubic centimetres of a decinormal solution of potassium chloride be injected into the dorsal lymph sacs of one of these frogs, and after twenty minutes the animal is killed, appropriate treatment, with the cobalt reagent, of a thin section of the fresh kidney made by the carbon dioxide freezing method, reveals in the cells of certain of the tubules a condensation of potassium salts in the cytoplasm immediately adjacent to the wall of the lumen. There is also a very slight diffuse reaction throughout the remainder of the cytoplasm, except in that part immediately adjacent to the external boundary of the tubule. In these cells the potassium injected into the lymph circulation is being excreted, and the condensation of the element at or near the surface of the lumen is evidence that there the tension is less than at the other extremity of the cell.

These facts are in their significance in line with some observations that I have made on the absorption of soluble salts by the intestinal mucosa in the guinea-pig. When the 'peptonate' of iron was administered in the food of the animal it was not unusual to find that in the epithelial cells of the villi the iron salt was distributed through the cytoplasm, but its concentration, as a rule, was greatest in the cytoplasm adjacent to the inner surface of the cell, from which it diffused into the underlying tissue. Here also, inferentially, surface tension is lower than elsewhere in the cell.

It would perhaps be unwise to form final conclusions at this stage in the progress of the investigation of the subject, but the results so far gained tempt one to adopt as a working hypothesis *that in the secreting or the excreting cell lower surface tension exists at its secreting or excreting surface than at any other point on the cell surface.* How this low surface tension is caused or maintained it is impossible to say, but, whatever the solution of the question may be, it is important to note that we must postulate the participation of this force in renal excretion in order to explain the formation of urines of high concentration. These have a high osmotic pressure, as measured by the depression of the freezing point, while the osmotic pressure of the blood plasma determined in the same way is low. On the principle of osmosis alone, as it is currently understood, this result is inexplicable, for the kinetic energy, as required in the gas theory of solutions, should not be greater, though it might be less, in the urine than in the blood. It

[1] Stoklasa gave the values in K_2O and Na_2O.

is manifest that in the formation of concentrated urines energy is expended. We know also from the investigations of Barcroft and Brodie that the kidney during diuresis absorbs much more oxygen per gram weight than the body generally, and that, assuming it is used in the combustion of a proteid, a very large amount of energy is set free, very much more indeed than is necessary. It has also been observed that a portion of the energy set free is found in a higher temperature in the excretion than obtains in the blood itself circulating through the kidney. This large expenditure of energy is, probably, a result of the physiological adaptation of the principle of the 'factor of safety,' which, as Meltzer has pointed out, occurs in other organs of the body.

In cell and nuclear division surface tension operates as a force, the action of which cannot be completely understood till we know more of the part played by the centrosomes and centrosphere. That this force takes part in cell reproduction has already been suggested by Brailsford Robertson. He has devised an ingenious experiment to illustrate its action. If a thread moistened with a solution of a base is laid across a drop of oil in which is dissolved some free fatty acid the drop divides along the line of the thread. When the latter is moistened with soap the drop divides in the same way and in the same plane. The soap formed in one case and present in the other, it is explained, lowers the surface tension in the equatorial plane of the drop, and this diminution results in streaming movement away from that plane which bring about the division. He suggests that in cell division there is a liberation of soaps in the plane of division which set up streaming movements from that plane towards the poles and terminating in the division of the cytoplasm of the cell.

I have observed in the cells of *Zygnema* about to divide a remarkable condensation of potassium in the plane of division. In the 'resting' cell of this *Alga* the potassium is, as a rule, more abundant in the cytoplasm near the transverse walls of the thread, and only traces of the element are to be found along the line of future division of the cell. But immediately after division has taken place the potassium is concentrated in the plane of division. This would seem to indicate that surface tension in the plane of division is, as postulated by the deduction from the Gibbs-Thomson principle, lower than it is on the longitudinal surface, and lower, especially, than it is on the previously formed transverse septa of the thread.

One must not, however, draw from this the conclusion that in all dividing cells surface tension is lower in the plane of division than it is elsewhere on the surface of the dividing structure. All that it means is that in the dividing cell of *Zygnema* the condition already exists along the plane of division, which subsequently makes for low surface tension in the cell membrane immediately adjacent to each transverse septum in the confervoid thread. If the evidence of low surface tension vanished immediately after division was complete, then it might be held that it determined the division. As it is, the low surface tension in this case is the result and not the cause of the division.

This conclusion is corroborated by the results of observations on the cells of the ovules of *Lilium* and *Tulipa*. The potassium salts in these are found condensed in minute masses throughout the cytoplasm. When division is about to begin the salts are shifted to the peripheral zone of the cytoplasm, and when the nuclear membrane disappears not a trace of potassium is now found in the neighbourhood of the free chromosomes, a condition which continues till after nuclear division is complete. The absence of potassium, the most abundant basic element in the cytoplasm, would indicate that soaps are not present, and appropriate treatment of such cells, hardened in formaline only, with Scarlet Red demonstrates that fats, including lecithins, are absent also. This would seem to show that high instead of low surface tension prevails about the nucleus during division. During the 'resting' condition of the nucleus this high tension is maintained, for, except in very rare cases, and these of doubtful character, there is no condensation of inorganic salts in the neighbourhood or on the surface of the nuclear membrane. It is also to be noted that the nucleus, with exceptions, the majority of which are found in the Protozoa, is of spherical shape, which also postulates that high surface tension obtains either in the cytoplasmic layer about the nucleus or in the nuclear membrane itself. It may also be suggested that high surface tension, and not the physical impermeability of the nuclear membrane, is the reason why the nucleus is, as I have often stated, wholly free from inorganic constituents.

It does not follow from all this that surface tension has nothing to do with cell division. If, as Brailsford Robertson holds, surface tension is lowered in the plane of division, then the internal streaming movement of the cytoplasm of each half of the cell should be towards that plane, and, in consequence, not separation but fusion of the two halves would result. The lipoids and soaps would indeed spread superficially on the two parts from the equatorial plane towards the two poles, and, according to the Gibbs-Thomson principle, they would not distribute themselves through the cytoplasm in the plane of division, except as a result of the formation of a septum in that plane. In other words, the septum has first to exist in order to allow the soaps and lipoids to distribute themselves in a streaming movement over its two faces. In Brailsford Robertson's experiment this septum is provided in the thread. If, on the other hand, surface tension is higher about the nucleus in and immediately adjacent to the future plane of division, then constriction of the nucleus in that plane will take place accompanied or preceded by an internal streaming movement in each half towards its pole and a consequent traction effect on the chromosomes which are thus removed from the equatorial plane. When nuclear division is complete then a higher surface tension on the cell itself limited to the plane of division would bring about there a separation of the two halves, a consequent condensation on each side of that plane of the substances producing the low tension elsewhere, and thereby also the formation of the two membranes in that plane.

In support of this explanation of the action of surface tension as a factor in division I have endeavoured to ascertain if, as a result of the Gibbs-Thomson principle, there is a condensation of potassium salts in the cytoplasm at the poles of a dividing cell, that is, where surface tension, according to my view, is low. The difficulty one meets here is that, in the higher plant forms, cells preparing to divide appear to be much less rich in potassium than those in the 'resting' stage, and under this condition it is not easy to get unambiguous results, while in animal cells potassium may even in the resting cell be very minute in quantity, as, for example, in *Vorticella*, in which, apart from the contractile stalk, it is limited to one or two minute flecks in the cytoplasm. Instances of potassium-holding cells undergoing division are, however, found in the spermatogonia of higher vertebrates (rabbit, guinea-pig), and in these the potassium is gathered in the form of a minute, and thin caplike layers at each pole of the dividing cell.

This of itself would appear to show that surface tension is less in the neighbourhood of the poles than at the equator of the dividing cell, but I am not inclined to regard the fact as conclusive, and a very large number of observations to that end must be made before certainty can be attained. I am, nevertheless, convinced that it is only in this way that we can finally determine whether differences of surface tension in dividing cells account, as I believe they do, for all the phenomena of cell division. The difficulties to be encountered in such an investigation are, as experience has shown me, much greater than are to be overcome in efforts to study surface tension in cells under other conditions, but I am in hopes that what I am now advancing will influence a number of workers to take up research in microchemistry along this line.

I must now discuss surface tension in nerve cells and nerve fibres. I have stated earlier in this address that I hold that the force concerned in the production of the nerve impulse by the nerve cell is surface tension. The very fact that in the repair of a divided nerve fibre the renewal of the peripheral portion of the axon occurs through a movement—a flowing outward, as it were—of the soft colloid material from the central portion of the divided fibre is, in itself, a strong indication that surface tension is low here and high on the cell body itself. This fact does not stand alone. I pointed out six years ago that potassium salt is abundant along the course of the axon and apparently on its exterior surface, while it is present but in traces in the nerve cell itself. In the latter chlorides also are present only in traces, and therefore sodium, if present, is there in more minute quantities, while haloid chlorine is abundant in the axon. Macdonald has also made observations as to the occurrence of potassium along the course of the axon, and has in the main confirmed mine. We differ only as to mode of the distribution of the element in the axon, and the manner in which it is held in the substance of the latter; but, whichever of the two views may be correct, it does not affect what I am now advancing. Extensive condensation

or adsorption of potassium salts in or along the course of the axon, while the nerve cell itself is very largely free from them, can have but one explanation on the basis of the Gibbs-Thomson principle, and that explanation is that surface tension on the nerve cell itself must be high while it is low on or in its axon.

The conclusions that follow from this are not far to seek. We know that an electrical displacement or disturbance of ever so slight a character occurring at a point on the surface of a drop lowers correspondingly the surface tension at that point. What a nerve impulse fundamentally involves we are not certain, but we do know that it is always accompanied by, if not constituted of, a change of electrical potential, which is as rapidly transmitted as is the impulse. When this change of potential is transmitted along an axon through its synaptic terminals to another nerve cell, the surface tension of the latter must be lowered to a degree corresponding to the magnitude of the electrical disturbance produced, and, in consequence, a slight displacement of the potassium ions would occur at each point in succession along the course of its axon. This displacement of the ions as it proceeded would produce a change of electrical potential, and thus account for the current of action. The displacement of the ions in the axon would last as long as the alteration of surface tension which gave rise to it, and this would comprehend not more than a very minute fraction of a second. Consequently, many such variations in the surface tension of the body of the nerve cell would occur in a second; and, as the physical change concerned would involve only the very surface layer of the cell, a minimum of fatigue would result in the cell, while little or none would develop in the axon.

It may be pointed out that in medullated nerve fibres the lipoid-holding sheath, in close contact as it is with the axon, must of necessity maintain on the course of the latter a surface tension low as compared with that on the nerve cell itself, which, as the synaptic relations of other nerve cells with it postulate, is not closely invested with an enveloping membrane. In non-medullated nerve fibres the simple enveloping sheath may function in the same manner, and probably, if it is not rich in lipoid material, in a less marked degree.

What further is involved in all this, what other conclusions follow from these observations, I must leave unexplained. It suffices that I have indicated the main points of the subject, the philosophical significance of which will appear to those who will pursue it beyond the point where I leave it.

In bringing this address to a close I am well aware of the fact that my treatment of the subjects discussed has not been as adequate as their character would warrant. The position which I occupy imposes limits, and there enters also the personal factor to account in part for the failure to achieve the result at which I aimed. But there is, besides, the idea that in applying the laws of surface tension in the explanation of vital phenomena I am proceeding along a path into the unknown which has been as yet only in a most general way marked out by pioneer investigators, and in consequence, to avoid mistakes, I have been constrained to exercise caution, and to repress the desire to make larger ventures from the imperfectly beaten main road. Perhaps, after all, I may have fallen into error, and I must therefore be prepared to recall or to revise some of the views which I have advanced here, should they ultimately be found wanting. That, however, as I reassure myself, is the true attitude to take. It is a far cry to certainty. As Duclaux has aptly put it, the reason why Science advances is that it is never sure of anything. Thus I justify my effort of to-day.

Notwithstanding this inadequate treatment of the subject of surface tension in relation to cellular processes, I hope I have made it in some measure clear that the same force which shapes the raindrop or the molten mass of a planet is an all-important factor in the causation of vital phenomena. Some of the latter may not thereby be explained. We do not as yet know all that is concerned in the physical state of solutions. The fact, ascertained by Rona and Michaelis, that certain sugars, which neither lower nor appreciably raise surface tension in their solutions, condense or are adsorbed on the surface of a solution system, is an indication that there are at least some problems with a bearing on vital phenomena yet to solve. Nevertheless, what we have gained from our knowledge of the laws of surface tension constitutes a distinct step in advance, and a more extended application of the Gibbs-Thomson principle may throw light on the causation of other vital phenomena. To that end a greatly developed science of

microchemistry is necessary. This should supply the stimulus to enthusiasm in the search for reactions that will enable us to locate with great precision in the living cell the constituents, inorganic and organic, which affect its physical state and thereby influence its activity.

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The following Reports were then read :—

1. *Report on Anæsthetics.*—See Reports, p. 268.

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2. *Report on the Ductless Glands.*—See Reports, p. 267.

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3. *Report on the Occupation of a Table at the Zoological Station, Naples.* See Reports, p. 165.

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4. *Report on Electromotive Phenomena in Plants.*—See Reports, p. 281.

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5. *Report on the Dissociation of Oxy-Hæmoglobin at High Altitudes.* See Reports, p. 280.

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6. *Report on the Effect of Climate upon Health and Disease.* See Reports, p. 290.

FRIDAY, SEPTEMBER 2.

The following Papers and Reports were read :—

1. *Discussion on Compressed Air Illness.* *Opening Remarks by* LEONARD HILL, *M.B.*, *F.R.S.*

Air dissolves in the body, according to Henry's law. The cause of the illness is the escape of nitrogen bubbles in the blood. Oxygen chemically combines with

the tissues, and does not contribute to the illness. The prevention is the arrangement of the decompression period, so that the nitrogen dissolved in the body can escape through the lungs without the formation of bubbles in the blood.

The blood is the carrier by which the tissues are saturated and desaturated with nitrogen. It is assumed that the blood is instantly saturated and desaturated on passing through the lungs. The Admiralty tables of stage decompression are based on this assumption.

Experiments by F. J. Twort, H. B. Walker, and the writer show that this is incorrect. The subject stays an hour at +45 lb. Free diuresis is established by drinking water. The bladder is emptied every seven minutes, after decompression in five minutes from +45 lb. to +15 lb. Analyses of the urine show equilibrium of the nitrogen after about fourteen minutes. It follows that the arterial blood is only desaturated in about that time.

The Admiralty tables and those of Mr. Japp (East River Tunnels, New York) are based on the supposition that the blood circulates about once a minute; on the relative mass of blood and tissues; on the relative solubility of nitrogen in blood and tissues; and on the supposition that 'quick' parts half saturate in about five minutes and 'slow' parts in seventy-five minutes.

The great difference between the circulation and pulmonary ventilation in states of rest and hard work has not been taken into account. The circulation may be six and even ten times faster during work. This upsets all calculations based on 'quick' and 'slow' parts. Saturation and desaturation are not at the same rate if carried out in the one case resting and in the other working. The decompression period can be shortened by making men work during it.

F. J. Twort and the writer have worked out the solubility of nitrogen in fat at +90 lb., and find Vernon's figures for 1 atm. almost hold good for 7 atm. Fat dissolves more than five times as much oxygen and nitrogen as water. These experiments confirming those of Greenwood and the writer on heavy and light rats, and these of Boycott and Damant on fatter and leaner guinea-pigs, show that fat men are unsuitable for compressed-air work.

It has been established by human experience that short exposures to high pressures are free from risk.

The Admiralty Committee, therefore, lays great stress on the danger of saturation of 'slow' parts, and says the danger increases with the length of shift. While the effect of work may turn a 'slow' into a 'quick' part, the effect of fatigue in long shifts complicates the problem. The writer regards the time required for saturation and desaturation of the blood and abdominal organs, such as the liver, as particularly the danger time.

Neither the tables of the goat experiments of Boycott, Damant, and Haldane, nor the tables of Keays concerning the 557,000 man-shifts at the East River Tunnels, give conclusive evidence that shifts of three hours are more dangerous than one and a half, or eight than three.

The variations in percentage of cases, even when calculated from groups of 3,000 to 4,000 man-shifts, are very large, *e.g.*, eight-hours' shift 0·43 per cent. May 1907, and 0·94 per cent. January 1907. Chance plays a very big *rôle*. The first three-hour shift gave 0·35 per cent. cases, and nine fatal or dangerous, in about 43,600 man-shifts; the second three-hour shift (after three hours' interval) gave 0·72 per cent. cases, and four dangerous or fatal, in the same number of man-shifts. The sum of cases for the six hours is 1·07 per cent. The percentage in 10,700 man-shifts of eight hours is 0·62. Two three-hour shifts with a three-hour interval appears, then, to be almost doubly as risky as one eight-hour shift, because it doubles the decompressions. The percentage of illness was 0·66, and death 0·0035, in 557,000 man-shifts, with a decompression rate of fifteen minutes from +29 to +33 lb.

Of the 3,692 cases among 10,000 men 89 per cent. were bends, 5 per cent. vertigo=about 95 per cent. non-dangerous; 1·26 per cent. pain and prostration, 2·16 per cent. paralysis, 1·62 per cent. dyspnœa, 0·46 per cent. collapse=about 5 per cent. dangerous.

The compression relieved 90 per cent., and of the rest all except 0·5 per cent. were partly relieved. The Admiralty table ordains a rate of 42 to 52 minutes stage decompression for +29 to +33 lb. The writer does not expect engineers to accept the Admiralty period in the face of the above figures. Eight thousand

five hundred man-shifts were decompressed from +40 lb. in 48 minutes, with 1·62 per cent. cases and no serious ones. The method was (1) +40 to +29 lb. in five minutes; (2) ten minutes' walking in +29 lb.; (3) +29 to +12·5 lb. in eight minutes; (4) ten minutes' walking in +12·5 lb.; (5) +12·5 to +0 in fifteen minutes. The Admiralty table ordains 92 minutes for this pressure. About half this time evidently is enough.

'Slow' parts produce bends which do not matter: they can be relieved by recompression.

Statistics of the results of 'uniform stage' decompression obtained on goats by Boycott, Damant, and Haldane; on guinea-pigs by Boycott and Damant; on rabbits, pigs, and goats by the writer and Greenwood, taken together, afford no convincing evidence of the superiority of either method. The pig is a better animal to compare with man than a goat. The fermentation of gas in the goat's stomach complicates the problem. Comparable pig figures show 4 severe or fatal cases in 20 uniform, 9 in 32 stage, 9 in 44 modified uniform (decompression rate slowing as pressure falls). The time of decompression was 90 to 110 minutes, the pressure +75 lb. Decompression in 37 to 45 minutes killed 4 out of 4 by stage; 4 out of 8 (and 3 severe cases) by uniform. These were small pigs, weighing 33½ lb. to 49 lb. F. J. Twort and the writer have determined the desaturation of water when decompressed from +90 to +20 lb. in 10 minutes; and either (1) left quiet, (2) shaken, (3) gently oscillated, the gas comes off without bubbling in 1 and 3. In the case of oil there is a slow steady formation of small bubbles (0·1 to 0·3 mm. in diameter). The unstudied conditions which control bubble formation in supersaturated solutions are of the first importance.

'Delayed' illness and varying susceptibility depend on these influences.

The varying percentage of fat in blood, chyle, liver, and the gaseous contents of the guts are factors. Ill-health, a debauch, rich feeding modify these conditions. (Fat, 3 to 11 per cent. in chyle, in liver 2 to 3·5 per cent. in richly fed, 19 to 24 per cent. in fatty infiltration.)

Experiments by M. Greenwood and the writer show that it is fairly safe to decompress pigs and goats from +75 to +18 lb. in 10 minutes, and from +18 to +0 in 20 minutes, after an interval of 80 to 100 minutes.

One death and no severe case resulted in 47 pigs weighing 50 to 100 lb.; 1 severe, 3 slight cases in 19 goats weighing 39 to 57 lb. To these may be added 4 pigs (56 to 100 lb.) safely decompressed from +60 lb. Decompression from +90 to +20 lb., followed by an interval of 105 to 120 minutes, gave unfavourable results in fat pigs weighing 81 to 115 lb.—viz., 7 deaths and 1 severe case in 27 pigs. The deaths occurred in the pigs which had the shortest interval, 105 to 110 minutes. Two of these deaths and the severe case were due to the pump stopping at +20 and the chamber rapidly leaking out.

Only one pig out of all showed symptoms at +20 lb. The pigs lie asleep and do not move. Six goats compressed after a big feed were all taken with great gaseous distension of the stomach at +20 lb.

By extending the interval to 140 to 150 minutes three goats (on a spare diet) were decompressed successfully time after time after exposure to +90 lb. for three to four hours. An interval of 30 to 50 minutes at +15 lb. proved safe for 12 goats and 1 pig (96 lb.), after compression to +50 lb.

Experiments by H. B. Walker, F. J. Twort, and the writer show that the breathing of oxygen for a few minutes at +15 lb. washes the excess of nitrogen out of the urine (and blood) quickly, while only a little oxygen passes into the urine. It is safe to breathe oxygen for some minutes at +15 lb., but inadvisable to breathe it at higher pressures because of the toxic effects of high pressures of oxygen.

Experiments of M. Greenwood and the writer show that a partial pressure of CO_2 up to 1 to 2 per cent. atm. is of no importance. Hot, moist atmospheres are exhausting. Many of the pig experiments were conducted with 4 to 5 per cent. atm. CO_2 in the chamber, and this was unfavourable, as the partial pressure fell on decompression, and lessened the pulmonary ventilation. Ventilation should be reduced in the lock. The cooling effect of decompression should be prevented, for it constricts the cutaneous vessels.

M. Greenwood and the writer were safely decompressed from +75 lb. by the uniform method—about 20 minutes per atm., four experiments. They were

actually exposed for about 30 minutes above +60 lb., and virtually exposed about 50 minutes. From +60 lb. they were safely decompressed, six experiments.

M. Greenwood was once decompressed safely from +92 lb. in 2 hours 17 minutes, after actual exposure above +75 lb. for about 30 minutes, and virtual exposure for about 55 minutes.

Hersent safely decompressed men after exposures of one hour in 26 minutes from +2½ atm.; in 46 minutes from +3 atm.; in 60 minutes from +3½ atm.; in 77 minutes from +4 atm.; in 100 minutes from +4½ atm.; in 150 minutes from +5 atm.; in 183 minutes from +5½ atm. Hersent safely used a method which is theoretically the worst—viz., +5 to +4 atm. in 45 minutes; +4 to +3 in 35; +3 to +2 in 30; +2 to +1 in 20, +1 to +0 in 15.

Damant and Catto were safely decompressed several times after short exposures by the stage method of the Admiralty Committee, *e.g.*, in 51 minutes, after 12 minutes, at +80 lb.; in 90 minutes, after 29 minutes, at +80 lb.; in 50 minutes, after 6 minutes, at +93½ lb.

These few high-pressure observations on men show that the stage method can be used safely after short exposures. The experience of divers has proved that a short uniform decompression in 20 minutes or less can be safely borne after exposure of not more than 15 to 20 minutes to +60 to +73 lb.—*e.g.*, Erostabe, Lambert. Much depends on the individual. They do not prove the far greater risk of the uniform method as claimed by the Admiralty Committee.

Conclusion.—One stage at +15 lb. would suffice for caisson workers up to +50 lb. Exercise and oxygen can be used to shorten the pause at +15 lb. A pause of 15 minutes at +10 lb. for +30 lb., and of 30 minutes at +15 lb. for +45 lb. would probably suffice, so long as a medical lock for recompression is at hand.

2. *The Cause of the Treppe.* *By* Professor FREDERIC S. LEE.

When the irritability of the excised muscle, as indicated by the threshold of stimulation, is determined at intervals throughout the course of the treppe it is found progressively to increase. Moreover, the irritability of muscle, as indicated by the threshold of stimulation, is increased by small quantities of fatigue substances, such as carbon dioxide and lactic acid. Under the influence of these same substances, also in small quantities, a muscle is able to perform greater contractions than before. It is, therefore, believed that the treppe represents increased irritability and actually increased working power, due to the action of small quantities of fatigue substances, among which may be included carbon dioxide, lactic acid, and possibly other compounds. The treppe is the physical expression of augmented vital processes.

According to Fröhlich, on the other hand, the augmentation of working power is not real, but only apparent. Fatigue begins with the commencement of the series of contractions. It is manifested by a slowing of relaxation, a diminution in the extent of contraction of the muscle elements, and a diminution in irritability. The experimental results of the present author do not support Fröhlich's theory.

3. *The Summation of Stimuli.* *By* Professor FREDERIC S. LEE *and* Dr. M. MORSE.

Professor Lee has found that muscle, when under the influence of small quantities of fatigue substances, such as carbon dioxide and lactic acid, and stimulated maximally, is able to perform greater contractions than before. He has explained the treppe as the physical expression of augmented vital processes, which are represented by increased irritability and increased working power, due to the action of small quantities of fatigue substances. This theory is now extended to the phenomenon of summation of stimuli. During the action of sub-minimal stimuli the irritability of muscle increases. Moreover, when a muscle is put under the influence of small quantities of carbon dioxide or lactic

acid its irritability is likewise increased, so that a previously ineffective stimulus is able at once to elicit contractions. Gotschlich has demonstrated that muscle, when sub-minimally stimulated for a period, becomes acid in reaction. It is, therefore, believed that the phenomenon of summation of stimuli is not fundamentally different from the treppe, and is due to the augmenting action of small quantities of fatigue substances.

4. *Influence of Intensity of Stimulus on Reflex Response.* *By* Professor C. S. Sherrington, *F.R.S., and* Miss S. C. M. Sowton.

5. *Constant Current as an Excitant of Reflex Action.* *By* Professor C. S. Sherrington, *F.R.S., and* Miss S. C. M. Sowton.

6. *Some Experiments on the Effects of X-rays in Therapeutic Doses on the growing Brains of Rabbits.* *By* Dr. Dawson Turner *and* Dr. T. G. George.

The authors spoke of the great importance of the subject, as a full dose of *x*-rays is frequently administered to children suffering from ringworm; attempt of the London County Council in March 1909 to make this treatment obligatory. Reference was made to experiments by Récamier and others which showed that the *x*-rays interfered with the growth of the bones and teeth. The question arose whether any change capable of being observed in the nervous system would be produced by a repetition of such doses of *x*-rays as are employed in the treatment of ringworm. The experiments of the authors were performed upon young rabbits. One-half of the head was exposed to and one-half protected from an ordinary *x*-ray dose. This dose was repeated three times, with an interval of a week between each dose. Of six rabbits chosen for the experiments only one survived for examination, so that no corroboration could be obtained of the changes observed. The microscopic changes in the brain were slight and inconclusive, but there were some undeniable gross changes—*e.g.*, the left or unexposed half of the brain was decidedly larger than the right or exposed half; the iris, first on the left and then on the right side, had undergone fatty degeneration; all the animals had lost weight during the exposures. It would therefore seem highly desirable that further investigation of this subject should be made.

7. *The Combination of certain Poisons with Cardiac Muscle.* *By* H. M. Vernon, *M.A., M.D.*

Tortoise hearts were perfused with oxygenated Ringer's solution to which known amounts of certain poisons were added. When alcohol, ether and chloroform were used the contraction height of the heart was depressed by a definite amount proportionate to the concentration, and after about ten minutes' poisoning the beats showed no further depression, though poisoning might be continued for another twenty minutes. On substitution of fresh saline the heart quickly recovered its initial contraction height, at a rate independent of the concentration of the poison used. Also the rate of recovery was about the same for all the three poisons mentioned. Hydrocyanic acid, at considerable dilutions, also depresses the cardiac contractions to a level proportionate to the concentration, but all strengths from 0·00125 to 0·01 per cent. HCN produce almost the same effect; or the effect is *not* proportionate to the concentration. Greater concentrations still depress the contractions further, but they permanently injure the heart. It is uncertain whether sodium fluoride acts like HCN or like

alcohol, &c., but it has a special action, as it excites enormous oscillations of tonus in the heart muscle, when washed out by fresh saline.

A heart once diminished in vitality no longer reacts in the same way, and a given concentration of poison produces a much more marked depression of contraction height, and the rate of recovery of the heart on washing out the poison is much slower.

8. *The Morphology and Nomenclature of the Blood Corpuscles.* *By* Professor C. S. Minot.

The Nutritive Effects of Beef Extract. *By* Professor W. H. Thompson, *M.D.*

(Preliminary Communication.)

Five experiments were carried out in the School of Physiology, Trinity College, Dublin. Of these, two were preliminary, one performed by Captain M. Corry, I.M.S., the other by Mr. A. Chance. The remainder were carried out by the writer. Dogs were used in all.

In the first of the series the animal was brought to constant weight on a diet of biscuit and lean meat. Beef extract ($2\frac{1}{2}$ grms.) was then substituted for double its weight of dog biscuit, and the effects observed for five days. This period was followed by one in which 5 grms. of the extract were given instead of the same weight of biscuit, and this by a final period in which $7\frac{1}{2}$ grms. of the extract replaced 5 grms. of dried dog biscuit.

In the remaining four experiments the dogs were brought to constant weight on a diet of dog biscuit alone. This first period was followed by other periods in which the extract in varying amount was added to the ration of biscuit. In Experiments IV. and V. the effects of the extract were further compared with those of boiled egg-white, added in varying quantities to the biscuit ration. All the experiments concluded with a period in which the diet of the first or preliminary period was again given.

The following results are taken from Exps. III., IV., and V., all carried out in the same way and two of them on the same animal.

Table showing Effect on the Animals' Weight.

—	Exp. III.	Exp. IV.	Exp. V.
Period 1 (Biscuit)	6·700 K	5·140 K	5·150 K
Period 2 (Biscuit + Extract) . .	6·800 ,,	5.185 ,,	(a) 5·230 ,, (b) 5·245 ,, (c) 5·250 ,,
Period 3 (Biscuit + Egg White)	No Egg white period in Exp. III. ,,	(a) 5·160 ,, (b) 5·170 ,, (c) 5·200 ,,	(a) 5·155 ,, (b) 5·165 ,, (c) 5·175 ,,
Period 4 (Biscuit)	6·700 ,,	Not observed	5·160 ,,

It will be seen that in Period 2 a considerable increase of weight occurred, amounting in Exp. III. to 100 grms., in Exp. IV. to 45 grms., and in Exp. V. from 80 to 100 grms. The quantities of the extract given were, in Exps. III. and IV. 5 grms. per day, while in Exp. V. the amount was increased from 5 grms. in Period (*a*) to 6 grms. in Period (*b*), and 7 grms. in Period (*c*). The amounts of coagulated egg-white (obtained by boiling eggs six to eight minutes and stripping off the white) varied as follows: In Exp. IV. the quantities per day were 20 grms. in (*a*), 40 grms. in (*b*), and 50 grms in (*c*). The corresponding quantities in Exp. V. were 30 grms. in (*a*), 50 grms. in (*b*), 70 grms. in (*c*).

The weight of dried organic solids given per day in the two forms of nitrogenous food—viz., the beef extract and the egg-white—was as follows :—

—	Exp. III.	Exp. IV.	Exp. V.
Beef Extract	1·9811 grm.	1·9103 grm.	(a) 1·9805 grm. (b) 2·3770 ,, (c) 2·7737 ,,
Egg White	—	(a) 2·868 ,, (b) 5·736 ,, (c) 7·170 ,,	(a) 4·302 ,, (b) 7·170 ,, (c) 10·038 ,,

Comparing this with the previous table, it will be seen that it required approximately four times as much organic nitrogenous food in the form of egg-white to give the same increase of weight as was given by the beef extract.

The nitrogenous metabolism is shown in the following table :—

Table showing Daily Intake and Output of Nitrogen (expressed in grammes) for corresponding Periods.

—	Food	Urine	Fæces
	Experiment III.		
Period 1 (Biscuit)	5·285	4·0591	1·1922
Period 2	{5·2850 0·3143}	4·3766	0·0746
Period 3	5·2850	4·1836	1·2490
	Experiment IV.		
Period 1	4·530	3·0805	0·8149
Period 2	{4·530 0·2885}	3.1958	0·4788
Period 3	(a) {4·5300 0·3760} (b) {4·5300 0·7510} (c) {4·5300 0·9390}	2·9740 3·3198 3·3626	0·9194
	Experiment V.		
Period 1	4·530	3·2354	1·0120
Period 2	(a) {4·5300 0·3134} (b) {4·5300 0·3761} (c) {4·5300 0·4388}	(a) 3·3221 (b) 3·6835 (c) 3·6508	0·7329
Period 3	(a) {4·5300 0·5637} (b) {4·5300 0·9395} (c) {4·5300 1·3153}	(a) 3·5399 (b) 3·7776 (c) 4·0295	0·6364

N.B.—In the food column of the above table the bracketed numbers indicate the nitrogen of the biscuit and of the extract respectively.

It will be seen in Exps. IV. and V. that a deficit of nitrogen exists, if the intake in Period 2 be compared with the output in urine and fæces. The quantity thus available for retention in the body amounted in Exp. IV. to 60 per cent,

and in Exp. V. to 15 per cent. of the extract nitrogen given. Further, on examining the nitrogen of the fæces, it will be seen that in all cases the effect of the extract was to lessen the amount excreted, and therefore to increase the assimilation of the biscuit food.

As regards the form in which the extra nitrogen was excreted in the urine during the periods of feeding with beef extract and egg-white, it was found that proportionately less appeared as urea and more as kreatinin and kreatin in the former than in the latter. The egg-white did not increase the total kreatinin or kreatin, on the contrary seemed to reduce the amount of these substances in the urine.

In Exp. V., Period 1 (biscuit), the urinary nitrogen contained 73·57 of urea and 3.87 per cent. of kreatinin. In Period 2 (extract), the corresponding amounts were 72·32 per cent. and 4·7 per cent. respectively; while in Period 3 (egg-white) the urinary nitrogen contained 74·22 per cent. of urea and 3·1 per cent. kreatinin.

The general conclusions seem to be that the beef extract used has both a direct and an indirect nutritive value, apart from any effect it may have as a vascular stimulant. The former leads to relatively large increase of weight in proportion to the amount of foodstuff given. The latter is manifested by a fuller utilisation of the other food constituents to which the extract is added, and is in accordance with Pavlov's observations to the effect that meat extracts promote an increased flow of active digestive juices. The experiments were undertaken at the request of the medical commissioner of the Local Government Board in Ireland with the object of ascertaining whether the extract in question had any nutritive value or not.

P.S.—It was made known to the Section that in the experiments a commercial extract was used, but as the proceedings of the British Association meetings appear in the Press next day, it was considered necessary to withhold the name until the results were communicated to some other scientific society and published elsewhere. There can be no harm in adding now that the extract of beef used was that known as 'Bovril.' The samples were bought on the market as required and were found on analysis to be very uniform in composition.—December 6, 1910.

10. *The Conditions necessary for Tetanus of the Heart.* *By* JOHN TAIT, *M.D.*

11. *Neurogenic Origin of Normal Heart Stimulus.* *By* JOHN TAIT, *M.D.*

12. *Report on Body Metabolism in Cancer.*—See p. 297.

13. *Report on Mental and Muscular Fatigue.*—See p. 292.

14. *Demonstration of Calorimeter.* *By* Professor J. S. MACDONALD, *B.A.*

MONDAY, SEPTEMBER 5.

Joint Discussion with Sections B and K on the Biochemistry of Respiration.

(i) *Problems of the Biochemistry of Respiration in Plants.* *By* Dr. F. F. BLACKMAN, *F.R.S.*

As an introduction to this conjoint meeting, a sketch may be given of the main problems of the biochemistry of respiration in plants.

Were a complete exposition of this subject possible it would include three main sections: (1) What is the nature of the chemical reaction or complex of reactions that constitutes respiration? (2) To what extent can this reaction in the cell be shown to conform to the laws of general chemistry, in the matter of reaction velocity, temperature-coefficients, mass of reacting substances, influence of katalysts and foreign substances? (3) What is the influence upon the progress of the reaction of the peculiar medium, protoplasm, in which it takes place?

(1) A summary statement of respiration takes the form of the equation for the complete oxidation of glucose. From this simple equation physiologists have been driven to make continually more and more complicated pictures of what actually happens intermediately in respiration.

The first complication was introduced by the discovery of 'anaerobic' respiration and the separation of oxidation-processes from anaerobic splitting of glucose. This raises the questions: What are these splitting products; do they form the first stage of normal respiration, and are the end products of splitting (such as alcohol) the bodies oxidised or are less stable precursors of alcohol oxidised in presence of air?

The second complication arises in connection with oxidation. None of the probable substances formed by splitting oxidise spontaneously to CO_2 and H_2O. Some special chemical machinery is needed to explain the oxidation. The simplest chemical oxidation is now regarded as a complex phenomenon, still more so oxidation in the cell. Oxidative agents are generally present, some of which may be true enzymes—oxidases—and others only carriers of oxygen; but there is the difficulty that aliphatic compounds are but little attacked by them, and the oxidation seems never to be complete.

Palladin's theory of respiratory chromogens maintains that these chromogens, which are aromatic substances, are oxidised by oxidases and then act as carriers of oxygen to the splitting products of glucose.

(2) The physical chemistry of the respiration reaction. (*a*) Influence of temperature. (*b*) Influence of concentration of the reacting substances, oxygen, protoplasmic catalyst, and sugar. An account of the writer's experiments on starvation and nutrition of leaves, the respiration of starchy and sweet potatoes. Hypothesis that normal respiration consists of two processes, a small 'protoplasmic' respiration, which cannot be suppressed without death, and a larger 'floating' respiration, which fluctuates with the sugar supply and can be abolished by starvation. (*c*) The effect of chemical 'stimuli' upon respiration. These act in several different ways which are of considerable theoretical interest.

(3) Protoplasm may be regarded as a honeycomb structure of colloidal semi-permeable septa. A medium of this nature introduces complications not found in reactions *in vitro*.

Alterations of internal permeability may affect the spatial separation of interacting substances and so change the magnitude of respiration and other processes.

The work of Lepeschkin has shown that variations of protoplasmic permeability, produced naturally by light and other causes, also by chloroform, etc., are important factors in cellular physiology.

The relation of respiration to the break-down of the specific organisation of protoplasm, as illustrated by long-continued starvation experiments with leaves.

(ii) *The Biochemistry of Respiration.* *By* Dr. H. M. Vernon.

Living tissues contain *oxygenases*, or substances which absorb molecular oxygen, bind it up to form peroxides, and so render it more active. They also contain *peroxidases*, or activators, which greatly increase the oxidising power of the oxygenases. Many, or perhaps all, the tissue constituents can be oxidised by means of these ferments acting together. Thus Fenton in 1894 showed that H_2O_2, in the presence of an activator such as $FeSO_4$, could easily oxidise tartaric acid; and Dakin has recently shown that it can oxidise amino acids, as $R.CH.NH_2.COOH$ to $NH_3+CO_2+R.CHO$. The aldehyde is then further oxidised, and is ultimately converted into CO_2+H_2O. All fatty acids from formic to stearic can undergo this oxidation. Carbohydrates can be similarly oxidised. Tissue respiration seems to be dependent on enzyme action, as it

is not altogether stopped in such an organ as the mammalian kidney by previously heating it to 60°, by freezing, or by the prolonged action of 1 per cent. NaF. H_2O_2, acting in presence of peroxidases, can likewise in some cases liberate CO_2, but no definite proof has as yet been obtained of such oxidation by oxygenase+peroxidase, probably because oxygenases are so unstable as to be destroyed very soon after a tissue is disintegrated.

The existence of aldehyde groupings in living tissues is supported by the fact that if an organ such as the kidney is poisoned with HCN, NaF, or $NaHSO_4$, its gaseous metabolism is temporarily lowered to a third the normal, but on perfusion with salt solution it gradually recovers the respiratory powers of unpoisoned kidneys. Now these poisons are known to be capable of forming loose additive compounds with aldehydes, but other poisons, which form no such compounds, permanently depress the gaseous metabolism.

Probably there is more than one grade of oxidising power by the tissues (*e.g.*, oxygenase only, and oxygenase+peroxidase). Thus, if the vitality of the tissues is depressed by the continued action of weak acids and alkalis, their CO_2-forming power is much more affected than their oxygen-absorbing power, and the respiratory quotient falls to 0·4. The same condition is produced quickly by poisoning with formaldehyde. Probably these poisons destroy the tissue peroxidase more rapidly than the oxygenase.

Doubtless other disintegrating mechanisms exist in the tissues which assist the oxidation processes. It is found, for instance, that the intermediate products of action of zymase on glucose can be oxidised in part to CO_2+H_2O by the action of H_2O_2+a peroxidase, whilst pure glucose cannot.

(iii) *Oxydases.* *By* E. Frankland Armstrong, *Ph.D.*, *D.Sc.*

Opinions are at present divided whether the oxydases are to be regarded as enzymes or as inorganic catalysts in a colloidal substrate.

Oxydase extracts can be subjected to far more drastic methods of purification than hydrolytic enzymes without destroying their activity. They invariably contain small traces of inorganic substances, generally manganese, iron, and calcium salts, and careful purification fails to remove these, though the amount of manganese bears no relation to the activity of the preparation. Their behaviour can be imitated by colloidal suspensions of some inorganic salts. They are far less selective in their action than the hydrolytic enzymes, tyrosinase, for example, acting on d-, l-, and dl-tyrosine apparently with equal ease, and also acting on substituted tyrosine compounds so long as they contain the phenolic hydroxyl group intact.

Euler's recent observation that laccase from *Medicago sativa* can be purified till it consists of a mixture of the calcium salts of polybasic hydroxy acids such as citric, malic, and mesoxalic acids is of great interest.

On the other hand, Bach takes the view that the inorganic salts are not an integral part of oxydases, and do not constitute their active principle. Their influence is analogous to that of ferrous sulphate on peroxides; the salts are only enabled to act because the oxydase has formed a peroxide. There is considerable evidence of the specific nature of oxydases and of the existence of different oxydases, *e.g.*, tyrosinase, laccase. Moreover, much of the evidence on the biological side is in favour of regarding the oxydases as enzymes, for example, that detailed in the following note.

(iv) *The Stimulation of Oxydases and Degenerative Enzymes in the Plant.* *By* E. Frankland Armstrong, *Ph.D.*, *D.Sc.*

The leaves of the *Aucuba japonica* go a remarkable black colour when exposed to the vapour of toluene, chloroform, ether, ethylacetate, alcohol, and many other organic substances. A detailed investigation has shown that certain inorganic salts in aqueous solution, such as cadmium iodide, mercuric chloride, sodium and potassium fluoride, ammonia, but not alkalies, and some organic acids, in particular benzoic and the higher homologues of acetic acid, produce the blackening, all the simple inorganic salts being ineffective.

The active substances are characterised by their possessing very little

affinity for water, and it is suggested that they are therefore able to penetrate the differential septa of the cell and disturb the osmotic conditions in the cell. Equilibrium is upset and hydrolysis takes place, the hydrolytic enzymes become functional, and a general degradation sets in. One outward manifestation of the degradation is the blackening generally attributed to oxidative changes. Another is the hydrolysis of glucoside present which, in the case of the cherry laurel leaf, can be observed by detecting the hydrogen cyanide formed. A third is the great increase produced in the amount of reducing sugar present in the leaf.

(v) *By* D. THODAY.

A small dose of chloroform produces a temporary increase in both the intake of oxygen and the evolution of CO_2. A large dose is immediately or ultimately fatal, and depresses the evolution of CO_2 at once. At the same time in *Tropæolum* the intake of O_2 is still more depressed, but in *Helianthus* and cherry laurel, with the darkening of the leaf there is a greatly increased intake of oxygen. The oxidation of tannins thus indicated, together with the hydrolysis of the cyanogenetic glucoside of cherry laurel, are made possible by an increase of permeability, which partially upsets the organisation of the cells, but does not immediately produce death. A similar but smaller increase of permeability may account for the stimulation produced by smaller doses.

TUESDAY, SEPTEMBER 6.

The following Papers were read :—

1. *The Origin of the Inorganic Composition of the Blood Plasma.* *By* Professor A. B. MACALLUM, *F.R.S.*

Analyses of inorganic composition of the blood serum in the dogfish (*Acanthias vulgaris*), the cod (*Gadus callarias*), and the pollock (*Pollachius virens*) have given results which show that the ratios of the potassium, calcium, and magnesium to the sodium are on the whole those which obtain in the blood of mammals as determined in Abderhalden's and Bunge's analyses. These with those of the sea water are :—

	Na	K	Ca	Mg
Dogfish	100	4·61	2·71	2·46
Pollock	100	4·33	3·10	1·46
Cod	100	9·50	3·93	1·41
Mammal (average)	100	6·69	2·58	0·80
Ocean	100	3·61	3·91	12·0

The amount of potassium in the blood serum of the cod as shown is high, but the excess is probably due to some laking of the red corpuscles, as, in spite of the care taken in the preparation of it, the serum was slightly tinged with hæmoglobin. Variations in the calcium are due to the different amounts absorbed and retained by the fibrin in its formation and subsequent shrinkage, but these are not marked. The only difference of note is in the magnesium, which in the dogfish is three times what it is in the mammal, but only one-fifth what it is in sea water, while in the cod and pollock it is midway in amount between the ratios found in the mammal and the dogfish.

These ratios seem to indicate that they are slight modifications of the ratios which prevailed in the blood serum of the ancestors of vertebrates. The high proportion of magnesium in the dogfish, the cod, and pollock may be explained as due to the action of the sea water, which is rich in this element, for Elasmobranchs have always been oceanic, *i.e.*, since their origin in the Silurian at the latest, and the Gadidæ (cod and pollock) have been resident in the ocean since the origin of Teleosts from a Ganoid form in the Cretaceous. This long association with the sea has given 1·77 per cent. of total salts in the dogfish and

1·28 per cent. in the cod and pollock, while in the mammal the total salts are in the neighbourhood of 0·90 per cent.

Analyses of the blood in the king crab (*Limulus polyphemus*) and of the lobster (*Homarus Americanus*) gave in total salts 2·982 and 2·852 per cent. respectively, which are approximately the concentrations of the sea waters of their habitat. The ratios of the elements as found were :—

	Na	K	Ca	Mg	SO_3	Cl
Limulus	100	5·62	4·06	11·20	13·33	186·9
Homarus	100	3·73	4·85	1·72	6·67	171·2
Aurelia flavidula .	100	5·18	4·13	11·43	13·18	185·5
Ocean	100	3·61	3·91	12·0	20·9	180·9

The remarkable agreement between the ratios in *Limulus* and *Aurelia*, and again between these and those of sea water, shows that the composition of the ocean determines the inorganic composition of the blood in *Limulus*, which with its ancestral forms has been oceanic since the beginning of the Cambrian. The only important differences in these ratios is to be found in the SO_3 in both forms, being not more than two-thirds of that in sea water.

In the lobster the ratios for the magnesium and the SO_3 are far behind those found in *Limulus*. The reason is that the resistance which the absorbing membranes in the lobster exercise towards the magnesium and the SO_3 has not been so much weakened as in *Limulus*.

The difference not only in the ratios of the elements but also in the concentrations of the total salts between *Limulus* and the dogfish, both of which, as pointed out, have always been oceanic, and between the lobster on the one hand and, on the other, the cod and pollock, all three of which have been oceanic since the Cretaceous, is to be referred to the character of the vertebrate kidney. The uniformity in inorganic composition of the blood plasma throughout vertebrates is due to the specific action of the vertebrate kidney, the primary and only function of which in eovertebrates was, apparently, to keep the inorganic composition of the blood uniform in all habitats. This and other facts make it necessary to regard the kidney as the most ancient and typical vertebrate organ, and to conclude that it acquired its characteristic function when the ocean had a saline concentration about one-third of that of the ocean of to-day, and when also the oceanic ratios were approximately those now found in vertebrate blood plasma.

The inorganic composition of the blood plasma may, consequently, be regarded as palæo-oceanic in character, an heirloom of life in the sea of remote geological time.

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2. *The Inorganic Composition of the Blood Plasma in the Frog after a long period of Inanition.* *By* Professor A. B. MACALLUM, *F.R.S.*

The blood plasma of the laboratory frog in spring gives a Δ ranging from −0·38° to −0·40° C. The salts in amount vary from 0·57 to 0·64 per cent., and they account for practically the whole of the Δ (−0·395° out of −0·40° C.). In consequence of this low concentration of the salts the blood as it is collected lakes spontaneously and more or less freely. This is probably the reason for the variations in volume of the red corpuscles in the blood in different frogs as observed, for the maximum volume as found with the hæmatocrite was 29 per cent. and the minimum 13 per cent.

The ratios of the potassium, calcium, and magnesium were approximately those found in mammals, except in the low value of the magnesium and in the potassium, the excess of which was due to laking.

Na		K		Ca		Mg
100	.. ..	12·7	.. ..	3·98	.. ..	0·305

The red corpuscles are rich in potassium, amounting to about 0·200 per cent. and apparently free from sodium salts. The sodium in the plasma ranges from 0·1874 to 0·1975 per cent., while the chlorine in two determinations from different samples gave 0·252 and 0·267 per cent.

The lowest Δ found by Dekhuyzen in the blood in the normal frog was −0·464°. The highest Δ determined by him in any other vertebrate was found by Dekhuyzen in *Tinca vulgaris* (−0·466°).

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3. *The Microchemistry of the Spermatic Elements in Vertebrates.* *By* Professor A. B. MACALLUM, *F.R.S.*

In the heads of the spermatic elements in the frog, guinea-pig, and rabbit practically no evidence of the presence of iron is to be obtained on keeping the alcohol-hardened material in contact with glycerine-ammonium sulphide reagent at 60° C. for days. In the nuclei of the spermatogonia and spermatocytes (rabbit), on the other hand, the chromatin contains 'masked' iron. The chromatin of the spermatids also gives evidence of its presence, but in a much less distinct degree. It is evident, therefore, that in the development of the spermatozoa from the spermatogonia the masked iron is eliminated.

The hexanitrite of cobalt and sodium applied as a reagent for potassium to the fresh spermatic elements reveals an extraordinary distribution of potassium in the vicinity of the head and in the middle piece. In the frog, as these elements are before their discharge into the duct, potassium occurs in a minute deposit in the cytoplasm at the very anterior point of the head. It is also distributed in the remains of the cytoplasm, as a cap-like deposit, covering the posterior end of the head. In the elements in the higher forms (*Homo*) it occurs in a more or less concentrated deposit about the posterior half of the head and in the anterior portion of the middle piece. Sometimes the deposit about the head is in the form of a distinct zonular band, sometimes the band is replaced by a zone of large granules, and behind this band there may be some minor or less distinct bands. The latter may also continue as a series into the middle piece proper. No potassium has been found in the posterior third of the middle piece.

The contents of the head do not contain any inorganic compounds. The potassium about the heads is contained in what would represent a part of the residue of the cytoplasm of the spermatogonium and spermatocyte.

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4. *The Afferent Nerves of the Eye Muscles.* *By* Dr. E. E. LASLETT, Professor C. S. SHERRINGTON, *F.R.S.*, *and* Miss F. TOZER.

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5. *Quantitative Estimation of Hydrocyanic Acid in Vegetable and Animal Tissues.* *By* Professor A. D. WALLER, *F.R.S.*—See *Report on Electromotive Phenomena in Plants*, p. 281.

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6. *Microphotographs of Muscle.* *By* Dr. MURRAY DOBIE.

Joint Discussion with Section L on Speech.—See p. 816.

SECTION K.—BOTANY.

PRESIDENT OF THE SECTION:
Professor JAMES W. H. TRAIL, M.A., M.D., F.R.S.

THURSDAY, SEPTEMBER 1.

The President delivered the following Address:—

THE honour conferred in the election to be President for the year of the Botanical Section of the British Association imposes the duty of preparing an address. I trust that my selection of a subject will not be attributed by anyone to a want of appreciation of the worth and importance of certain sides of botanical research to which I shall have less occasion to refer. These have been eloquently supported by former Presidents, and I take this opportunity to express the thanks I owe for the benefit received from their contributions to the advancement of the science of botany. They have told us of the advance in departments of which they could speak as leaders in research, and I do not venture to follow in their steps. My subject is from a field in which I have often experienced the hindrances of which I shall have to speak, both in personal work and still more as a teacher of students, familiar with the many difficulties that impede the path of those who would gladly give of their best, but find the difficulties for a time almost insurmountable, and who are too frequently unable to spare the time or labour to allow of their undertaking scientific investigations that they might well accomplish, and in which they would find keen pleasure under other conditions. Those whose tastes lie in the direction of studying plants in the field rather than in the laboratory are apt to find themselves hampered seriously if they seek to become acquainted with the plants of their own vicinity; and, if they wish to undertake investigations in the hope of doing what they can to advance botanical science, they may find it scarcely possible to ascertain what has been already done and recorded by others.

For a time the knowledge of plants was too much confined to the ability to name them according to the system in vogue and to a knowledge of their uses, real or imagined. The undue importance attached to this side of the study, even by so great a leader as Linnæus, naturally led to a reaction as the value of other aspects of botany came to be realised, and as improvements in the instruments and methods of research opened up new fields of study. The science has gained much by the reaction; but there is danger of swinging to the other extreme and of failing to recognise the need to become well acquainted with plants in their natural surroundings. The opportunities for study in the laboratory are so great and so much more under control, and the materials are so abundant and of so much interest, that there is for many botanists a temptation to limit themselves to such work, or at least to regard wor ikn the field as subordinate to it and of little value. It is scarcely necessary to point out that each side is insufficient alone. Yet some find more pleasure in the one side, and do well to make it their chief study; while they should recognise the value of the other also, and learn from it.

It is especially on behalf of the work in the field that I now wish to plead. There are few paths more likely to prove attractive to most students. The study of the plants in their natural environments will lead to an understanding of their

nature as living beings, of their relations to one another and to other environments, of the stimuli to which they respond, and of the struggle for existence that results in the survival of certain forms and the disappearance of others. In this way also will be gained a conception of the true meaning and place of classification as an indispensable instrument for accurate determination and record, and not as an end in itself. To one that has once gained a true insight into the pleasure and worth of such studies, collections made for the sake of mere possession or lists of species discovered in a locality will not suffice. Many questions will arise which will prove a constant source of new interest. From such studies a deep and growing love for botany has in not a few cases arisen.

The British flora has interested me for upwards of forty years, and has occupied much of my attention during that time—not only as desirous to aid by my own efforts to extend our knowledge of it, but also, as a teacher, seeking to assist my students to become able to do their parts also, and making use of the materials within reach to enable me to help them. Thus our present knowledge of the plants of our own country has become known to me, and the difficulties of acquiring that knowledge have also become known through both my own experience and those of my students. The nature of the hindrances and difficulties that at present bar the way has also become familiar, as well as the steps to be taken to clear some of them away and to make the path less difficult to those who come after us; and I have also gained a fairly good acquaintance with the means at the command of students of the floras of other countries, so as to have a standard for comparison in the estimate to be formed of the condition of matters in our own country.

In how far is the present provision for the study of the flora of the British Islands sufficient and satisfactory?

I venture to hope that the subject will be regarded as among those for the consideration of which the British Association was formed, and that a favourable view will be taken of the conclusions which I take this opportunity to lay before you. What, then, is the present provision for the study of our plants? Since the days of Morrison and Ray there have been many workers, especially during the past century; and an extensive literature has grown up, in the form both of books and of papers, the latter more or less comprehensive, in the scientific journals and in the transactions of societies. These papers contain much that is of great value; but, owing to the absence of any classified index, most of the information in it is beyond the reach of anyone, except at the expenditure of much time and labour. The constantly increasing accumulation of new publications makes the need for a classified index always more urgent; for the mass of literature is at present one of the greatest obstacles to the undertaking of new investigations because of the uncertainty whether they may not have been already undertaken and overlooked through want of time or opportunity to search the mass exhaustively.

While the early writers of descriptive floras sought to include every species of plant known to occur in Britain, this has not been attempted during the past seventy or eighty years, and instead of one great work we now have monographs of the greater groups, such as Babington's 'Manual' and Hooker's 'Student's Flora' of the vascular plants, Braithwaite's 'Mossflora,' &c. Local floras still, in a good many cases, aim at including all plants known to grow apparently wild in the districts to which they refer; but they are often little more than lists of species and varieties and of localities in which these have been found. In some, however, there are descriptions of new forms and notes of general value, which are apt to be overlooked because of the place in which they appear.

The early works were necessarily not critical in their treatment of closely allied species and varieties, but they are valuable as giving evidence of what plants were supposed to be native in England when they were published. Even the works that were issued after Linnæus had established the binominal nomenclature for a time related almost wholly to England. Sibbald in 'Scotia Illustrata' (1684) enumerated the plants believed by him to be native in Scotland, and of those then cultivated. Between his book and Lightfoot's 'Flora Scotia,' published in 1777, very little relating to the flora of Scotland appeared. Irish plants were still later in being carefully studied.

The floras of Hudson, Withering, Lightfoot, and Smith, all of which include

all species of known British plants, follow the Linnæan classification and nomenclature in so far as the authors were able to identify the Linnæan species in the British flora. 'English Botany,' begun in 1795, with plates by Sowerby and text by Smith, was a work of the first rank in its aim of figuring all British plants and in the excellence of the plates; but it shared the defect of certain other great floras in the plates being prepared and issued as the plants could be procured, and thus being without order. Its cost also necessarily put it beyond the reach of most botanists, except those that had the advantage of access to it in some large library. A second edition, issued at a lower price, and with the plants arranged on the Linnæan system, was inferior to the first, in the plates being only partially coloured and in having the text much curtailed. The so-called third edition of the 'English Botany,' issued 1868-86, is a new work as far as the text is concerned, that being the work of Dr. Boswell Syme, who made it worthily representative of its subject; but the plates, with few exceptions, are reissues of those of the first edition, less perfect as impressions and far less carefully coloured; and this applies with still greater force to a reissue of the third edition a few years ago. This edition, moreover, included only the vascular plants and Characeæ. As this is the only large and fully illustrated British flora that has been attempted, it is almost needless to add that in this respect provision for the study of the flora of our islands is far behind that of certain other countries, and very notably behind that made in the 'Flora danica.'

Turning next to the provision of less costly aids to the study of British plants, we have manuals of most of the larger groups. The vascular plants are treated of in numerous works, including a considerable number of illustrated books in recent years, inexpensive but insufficient for any but the most elementary students. Fitch's outline illustrations to Bentham's 'Handbook to the British Flora,' supplemented by W. G. Smith, were issued in a separate volume in 1887, which is still the best for use in the inexpensive works of this kind. Babington's 'Manual,' on its first appearance in 1843, was gladly welcomed as embodying the result of careful and continued researches by its author into the relations of British plants to their nearest relatives on the Continent of Europe; and each successive issue up to the eighth in 1881 received the careful revision of the author, and contained additions and modifications. In 1904 a ninth edition was edited, after the author's death, by H. and J. Groves; but, though the editors included notes left by Professor Babington prepared for a new edition, they were 'unable to make alterations in the treatment of some of the critical genera which might perhaps have been desirable.' The 'Student's Flora of the British Islands,' by Sir J. D. Hooker, issued in 1870, took the place of the well-known 'British Flora' (1830, and in subsequent editions until the eighth in 1860, the last three being issued in collaboration by Sir W. J. Hooker and Professor Walker Arnott). The third edition of the 'Student's Flora' appeared in 1884, and there has been none since. Mr. F. N. Williams' 'Prodromus Floræ Britannicæ,' begun in 1901, of which less than one-half has yet appeared, though a work of much value and authority, is scarcely calculated for the assistance of the ordinary student; and Mr. Druce's new edition of Hayward's 'Botanist's Pocket Book' 'is intended merely to enable the botanist in the field to name his specimens approximately, and to refresh the memory of the more advanced worker.' In all the books that are intended for the use of British botanists, apart from one or two recently issued local floras, the classification is still that in use in the middle of last century, even to the extent in the most of them of retaining Coniferæ as a division of Dicotyledones. Apart from this, the critical study of British plants has led to the detection of numerous previously unobserved and unnamed forms, which find no place in the 'Student's Flora,' and are only in part noticed in the recent edition of the 'Manual.'

The 'Lists' of vascular plants of the British flora that have recently been issued by Messrs. Rendle and Britten, by Mr. Druce, and as the tenth edition of the 'London Catalogue of British Plants' are all important documents for the study of the British flora; but they illustrate very forcibly certain of the difficulties that beset the path of the student eager to gain a knowledge of the plants of his native land. In these lists he finds it scarcely possible to gain a clear idea of how far the species and varieties of the one correspond with those of the other, owing to the diversities of the names employed. It would be a great

boon to others as well as to students were a full synonymic list prepared to show clearly the equivalence of the names where those for the same species or variety differ in the different lists and manuals. Probably in time an agreement will be generally arrived at regarding the names to be accepted, but that desirable consummation seems hardly yet in sight. Meantime the most useful step seems to be to show in how far there is agreement in fact under the different names.

Among the Cryptogams certain groups have fared better than the higher plants as regards both their later treatment and their more adequate illustration by modern methods and standards. Several works of great value have dealt with the mosses, the latest being Braithwaite's 'British Moss-flora,' completed in 1899. The Sphagna were also treated by Braithwaite in 1880, and are to be the subject of a monograph in the Ray Society's series. The liverworts have been the subject also of several monographs, of which Pearson's is the fullest.

Among the Thallophyta certain groups have been more satisfactorily treated than others—*e.g.* the Discomycetes, the Uredineæ and Ustilagineæ, the Myxomycetes, and certain others among the fungi, and the Desmidiaceæ among the algæ; but the Thallophyta as a whole are much in need of thorough revision to place them on a footing either satisfactory or comparable to their treatment in other countries.

Of the Thallophyta many more of the smaller species will probably be discovered within our islands when close search is made, if we may judge by the much more numerous forms already recorded in certain groups abroad, and which almost certainly exist here also; but among the higher plants it is not likely that many additional species will be discovered as native, yet even among these some will probably be found. It is, however, rather in the direction of fuller investigation of the distribution and tendencies to variation within our islands that results of interest are likely to be obtained.

The labours of H. C. Watson gave a very great stimulus to the study of the distribution of the flora in England and Scotland, and the work he set on foot has been taken up and much extended by numerous botanists in all parts of the British Islands. It is largely owing to such work and to the critical study of the flora necessary for its prosecution that so many additions have been made to the forms previously known as British. Many local works have been issued in recent years, often on a very high standard of excellence. Besides these larger works scientific periodicals and transactions of field clubs and other societies teem with records, some of them very brief, while others are of such size and compass that they might have been issued as separate books. A few of both the books and papers are little more than mere lists of names of species and varieties observed in a locality during a brief visit; but usually there is an attempt at least to distinguish the native or well-established aliens from the mere casuals, if these are mentioned at all. In respect of aliens or plants that owe their presence in a district to man's aid, intentional or involuntary, their treatment is on no settled basis. Every flora admits without question species that are certainly of alien origin, even such weeds of cultivated ground as disappear when cultivation is given up, as may be verified in too many localities in some parts of our country. Yet other species are not admitted, though they may be met with here and there well established, and at least as likely to perpetuate their species in the new home as are some native species.

Comparatively few writers seek to analyse the floras of the districts treated of with a view to determine whence each species came and how, its relation to man, whether assisted by him in its arrival directly or indirectly, whether favoured or harmfully affected by him, its relations to its environment—especially to other species of plants and to animals, and other questions that suggest themselves when such inquiries are entered on. It is very desirable that a careful and exhaustive revision of the British flora should be made on these and similar lines. In such a revision it is not less desirable that each species should be represented by a good series of specimens, and that these should be compared with similar series from other localities within our islands, and from those countries from which it is believed that the species originally was sprung. Such careful comparison would probably supply important evidence of forms being evolved in the new environments, differing to a recognisable degree from the ancestral types, and tending to become more marked in the more distant and longer isolated localities. An

excellent example of this is afforded by the productive results of the very careful investigation of the Shetland flora by the late Mr. W. H. Beeby.

Within recent years excellent work has been done in the study of plant associations, but the reports on these studies are dispersed in various journals (often not botanical), and are apt to be overlooked by, or to remain unknown to, many to whom they would be helpful. The same is true in large measure of the very valuable reports of work done on plant-remains from peat-mosses, from lake deposits, and from other recent geological formations, researches that have cast such light on the past history of many species as British plants, and have proved their long abode in this country. Mr. Clement Reid's 'Origin of the British Flora,' though published in 1899, has already (by the work of himself and others) been largely added to, and the rate of progress is likely to become still more rapid. Among the fruits and seeds recorded from interglacial and even from preglacial deposits are some whose presence could scarcely have been anticipated, *e.g. Hypecoum procumbens*, in Suffolk. Some of the colonists, or aliens now almost confined to ground under cultivation, have been recorded from deposits that suggest an early immigration into the British Islands. While much remains to be discovered, it is desirable that what is already established should find a place in the manuals of British botany.

Apart from the descriptive and topographical works and papers on our flora, there is a serious lack of information gained from the study of our British plants. Although a few types have received fuller study, we have little to compare with the work done in other countries on the structure and histology of our plants, on the effects of environment, on their relations to other species and to animals, and on other aspects of the science to which attention should be directed. On these matters, as on a good many others, we gain most of what information can be had not from British sources, but from the literature of other countries, though it is not wise to assume that what is true elsewhere is equally true here. It is as well, perhaps, that for the present such subjects should find scanty reference in the manuals in ordinary use; but, when trustworthy information has been gained within the British Islands, under the conditions prevailing here, these topics should certainly not be passed over in silence. Students of the British flora have as yet no such works of reference as Raunkjaer's book on the Monocotyledons of Denmark or the admirable 'Lebensgeschichte der Blütenpflanzen Mitteleuropas,' at present being issued by Drs. Kirchner, Loew, and Schröter.

In a complete survey of the British botany there must be included the successive floras of the earlier geological formations, though they cannot as yet be brought into correlation with the recent or existing floras. In the brilliant progress made recently in this field of study our country and the British Association are worthily represented.

The present provision for the study of the British flora and the means that should be made use of for its extension appear to be these :—

Much excellent work has already been accomplished and put on record towards the investigation of the flora, but much of that store of information is in danger of being overlooked and forgotten or lost, owing to the absence of means to direct attention to where it may be found. A careful revision of what has been done and a systematic subject-index to its stores are urgently required.

The systematic works treating of the flora are in great part not fully representative of the knowledge already possessed, and require to be brought up to date or to be replaced by others.

Great difficulty is caused by the absence of an authoritative synonymic list that would show as far as possible the equivalence of the names employed in the various manuals and lists. There is much reason to wish that uniformity in the use of names of species and varieties should be arrived at, and a representative committee might assist to that end; but, in the meantime, a good synonymic list would be a most helpful step towards relieving a very pressing obstacle to progress.

There is need for a careful analysis of the flora with a view to determining those species that owe their presence here to man's aid, intentional or unconscious; and the inquiry should be directed to ascertain the periods and methods of introduction, any tendencies to become modified in their new homes, their subsequent relations with man, and their influence on the native flora, whether

direct or by modifying habitats, as shown by *Lupinus nootkatensis* in the valleys of rivers in Scotland.

Those species that there is reason to regard as not having been introduced by man should be investigated as regards their probable origins and the periods and methods of immigration, evidence from fossil deposits of the period during which they have existed in this country, their constancy or liability to show change during this period, their resemblance to or differences from the types in the countries from which they are believed to have been derived, or the likelihood of their having originated by mutation or by slow change within the British Islands, and their relation to man's influence on them (usually harmful, but occasionally helpful) as affecting their distribution and permanence.

The topographical distribution, though so much has been done in this field during the past sixty or seventy years, still requires careful investigation, to determine not merely that species have been observed in certain districts, but their relative frequency, their relations to man (natives of one part of our country are often aliens in other parts), whether increasing or diminishing, altitudes, habitats, &c. From such a careful topographical survey much should be learned of the conditions that favour or hinder the success of species, of the evolution of new forms and their relation to parent types in distribution, especially in the more isolated districts and islands, and of other biological problems of great interest. A most useful aid towards the preparation of topographical records would be afforded by the issue at a small price of outline maps so as to allow of a separate map being employed for recording the distribution of each form.

A careful study of the flora is also required from the standpoint of structure and development, with comparison of the results obtained here with those of workers in other countries where the same or closely allied species and varieties occur. It is also needed in respect of the relations between the plants and animals of our islands, both as observed here and in comparison with the already extensive records of a similar kind in other countries. On such topics as pollination, distribution of seeds, and injuries inflicted by animals and galls produced by animals or plants we have still to make use very largely of the information gained abroad; and the same holds good with regard to the diseases of plants.

While 'English Botany' in its first edition was deservedly regarded as a work of the first rank among floras, it has long been defective as representing our present knowledge of British plants, and it has not been succeeded by any work of nearly equal rank, while other countries now have their great floras of a type in advance of it. There is need for a great work worthy of our country, amply illustrated so as to show not only the habit of the species and varieties, but also the distinctive characters and the more important biological features of each. Such a flora would probably require to be in the form of monographs by specialists, issued as each could be prepared, but as part of a well-planned whole. It should give for each plant far more than is contained in even the best of our existing British floras. Means of identification must be provided in the description, with emphasised diagnostic characters; but there should also be the necessary synonymy, a summary of topographical distribution, notes on man's influence upon distribution, abundance, &c., on any biological or other point of interest in structure or relations to habitat, environment, associated animals or plants, diseases, &c. Local names, uses, and folklore should also be included; and for this the need is all the greater, because much of such old lore is rapidly being forgotten and tends to be lost. In a national flora there should be included an account of the successive floras of former periods, and, as far as possible, the changes that can be traced in the existing flora from its earliest records to the time of issue should be recorded.

A flora of this kind would not only afford the fullest possible information with regard to the plant world of the British Islands at the date of issue, but would form a standard with which it could be compared at later periods, so as to permit of changes in it being recognised and measured. In the meanwhile the production of such a flora can be regarded only as an aim towards which to press on, but which cannot be attained until much has been done. But while the fulfilment must be left to others, we can do something to help it on by trying to remove difficulties from the way, and to bring together materials that may be used in its construction.

I have sought to call attention to the difficulties that I have experienced and to

directions in which progress could be made at once, and to provision which should be made for the advancement of the study of the British flora with as little delay as possible. There is, I feel assured, the means of making far more rapid and satisfactory progress towards the goal than has yet been accomplished. Many persons are interested in the subject, and would gladly give their aid if they knew in what way to employ it to the best purpose. As a nation we are apt to trust to individual rather than to combined efforts, and to waste much time and labour in consequence, with discouragement of many who would gladly share the labour in a scheme in which definite parts of the work could be undertaken by them.

I believe that a well-organised botanical survey of the British Islands would give results of great scientific value, and that there is need for it. I believe, also, that means exist to permit of its being carried through. There is no ground to expect that it will be undertaken on the same terms as the Geological Survey. A biological survey must be accomplished by voluntary effort, with possibly some help towards meeting necessary expenses of equipment from funds which are available for assistance in scientific research. Is such a survey of it an object fully in accord with the objects for which the British Association exists? In the belief that it is so, I ask you to consider whether such a survey should not be undertaken; and, if you approve the proposal, I further ask that a committee be appointed to report on what steps should be taken towards organising such a survey, and preparing materials for a national flora of the British Islands.

The following Papers were read:—

1. *On the Function and Fate of the Cystidia of* Coprinus atramentarius. *By* Professor A. H. Reginald Buller, *D.Sc., Ph.D., F.R.S.C.*

Brefeld,[1] in giving an account of the life-history of *Coprinus stercorarius*, made the suggestion that the cystidia which he observed in that species may possibly act as props to keep the gills, when stretching, from pressing against one another.

Hitherto the fate of the cystidia of the Coprini has been a mystery. Worthington Smith[2] stated that the cystidia are male organs, that they fall to the ground, and that they there liberate spermatozoa, which fertilise the spores.

In the light of my recent discoveries concerning the mode of liberation of the spores of the Coprini,[3] I have investigated the function and fate of the cystidia of *Coprinus atramentarius*, and have come to the following conclusions:—

The gills of *Coprinus atramentarius* are of great width and of extreme thinness, and consequently are very flexible. Numerous long cystidia stretch between and connect adjacent gills, the general surfaces of which thus become separated by an interlamellar space about 0·10 mm. wide. The cystidia serve as props, firstly, to keep the gills from touching one another during spore development; and, secondly, to provide sufficient interlamellar space for the free escape of the spores from between the gills during their discharge.

The cystidia do not drop out of the gills when mature. Their disappearance is due to auto-digestion. Excluding the cystidia, the gills undergo auto-digestion from below upwards in the manner that I[4] have already described for *Coprinus comatus*. Each cystidium begins to undergo auto-digestion as soon as it comes to be situated about 0·5 mm. above the upwardly progressing general zone of auto-digestion, and about forty minutes or so before the basidia and paraphyses in its immediate vicinity. During their auto-digestion the cystidia become progressively thinner, their fluid-contents are apparently absorbed by neighbouring cells, and they are finally withdrawn in a much reduced state to the gill sides, where their destruction is completed.

The cystidia, owing to their early auto-digestion, never persist until the

[1] O. Brefeld, *Untersuchungen*, Heft III., 1887, pp. 57 and 58.
[2] W. Smith, *Grevillea*, vol. iv., 1875–76, p. 60; also vol. x., 1881, p. 78.
[3] A. H. R. Buller, *Researches on Fungi*, London, 1909, pp. 196–215.
[4] *Loc. cit.*

upwardly progressing zone of spore discharge reaches them. Their prop function, however, is retained up to the last possible moment, and they disappear just in time to prevent the falling spores from striking and adhering to them.

In a number of other species of Coprinus the cystidia are removed from the gills during spore discharge by a process of auto-digestion similar to that which occurs in *C. atramentarius*.

2. *Asexual Reproduction in a Species of* Saprolegnia. *By* A. E. Lechmere, *M.Sc.*

A species of Saprolegnia was kept in pure culture in various media, but it proved impossible to obtain the formation of sexual organs. It has, therefore, not been possible to identify the species. The cultures were, however, of interest because of the variety of methods of asexual reproduction shown by them when grown under different conditions. Methods of asexual reproduction were observed in this one species which were regarded by earlier authors as characterising six different genera of the family.

3. *On Pseudomitosis in* Coleosporium. *By* Professor V. H. Blackman, *M.A.*

A form of nuclear division intermediate between mitosis and amitosis is to be observed in the divisions of the teleutospore in *Coleosporium Tussilaginis*. A well-marked spindle, centrosomes, and polar radiations are present, but the spireme which appears after nuclear fusion disappears again, and the chromatin becomes granular. The granular material becomes arranged on the spindle, and is then drawn apart towards the poles without the formation of chromosomes.

4. *Chromosome Reduction in the Hymenomycetes. By* Harold Wager, *F.R.S.*

The nucleus of the basidium is formed by the fusion of two nuclei (Wager, 1892), rarely by three or four (Wager, 1893; Maire, 1900). The presence of six or eight nuclei in a basidium as described by Rosen (1892) has not been observed, but some light is thrown upon Rosen's observations by the appearances presented in *Mycena galericulata*. In this species the nuclei both of the hyphae and the young basidium constantly show three or four chromatin masses in each nucleus, probably chromosomes, and in some cases, especially in the basidium, where the nuclear membrane is not clearly seen, we get an appearance of six to eight minute deeply staining nuclei, which correspond perfectly with the description of the nuclei of the fungi given at about the date of Rosen's paper by Schmitz and other observers.

The fusion of more than two nuclei in the basidium appears to be an abnormal, and not a normal, occurrence, as Dangeard has maintained.

The nuclei in the young basidium are extremely small. Previous to fusion they increase much in size, and in some cases they appear to extrude a quantity of chromatin, in the form of a nucleolus-like body, into the cytoplasm.

The number of chromosomes in the vegetative nuclei appears to be four. These are constantly seen in *Mycena galericulata*, both in the hyphae and in the young basidium. After the extrusion of the chromatin the young basidial nuclei show the normal structure of a resting nucleus with a faint nuclear network and a nucleolus. In this stage they fuse.

There was no direct evidence of conjugate division in the hyphae. In *Stropharia stercorarius* it was clear that conjugate division was possible, but in some other forms it was just as clear that the fusion nuclei of the basidium might be sisters.

After fusion both the basidium and its nucleus increase very much in size and the cytoplasm stains intensely. The nuclear network becomes very distinct, and in some cases appeared to form a nearly continuous spireme. The nuclear thread breaks up into eight segments, out of which the minute deeply staining

chromosomes arise by a condensation of the chromatin. At about the stage of the segmentation of the nuclear thread contraction figures can be observed. Some of the nucleolar chromatin appears to be taken up by the chromosomes, but the nucleoli themselves are extruded into the cytoplasm when division takes place.

The spireme often exhibits a folding at the periphery of the nucleus as described by Farmer and Moore in the nuclei of higher plants, but this did not resolve itself into bent and twisted segments, although appearances were observed which might have been interpreted in this way.

Reduction is brought about simply by the distribution of the chromosomes into groups of four each to the two daughter nuclei at the first division of the basidial nucleus. This apparently corresponds, therefore, to the brachymeiotic phase in the ascus as described by Miss Fraser, and seems to indicate that a sexual fusion necessitating a meiotic phase is absent. The second division in the basidium appears to be normal, in that four chromosomes are produced, which divide into two groups of four each to form the nuclei which will ultimately pass into the spores. The four chromosomes in the daughter nuclei were in most cases very clearly seen at the poles of the spindle. In the reconstitution of the daughter nuclei the chromosomes first of all fused together, and out of this fused mass the nuclear network and the nucleolus were differentiated.

Clear indications of the four chromosomes were also seen in the nuclear division in the spores.

5. *Some Observations on the Silver-Leaf Disease of Fruit Trees.* *By* F. T. Brooks, *M.A.*

This disease attacks plum trees more frequently than any other kind of fruit tree. Apple and cherry trees are occasionally affected, and I have recently found a few red-currant and gooseberry bushes attacked by this disease.

As the name of the disease implies, the foliage of affected plants presents a silvery appearance in contrast with the dark green colour of healthy leaves. At the commencement of attack a single branch usually becomes affected, but sooner or later the entire foliage assumes a silvery appearance. After an attack during one or more seasons some of the branches begin to die, and ultimately the whole tree succumbs. This disease seems to be rapidly increasing in frequency, and in some fruit plantations of Cambridgeshire nearly 10 per cent. of the plum trees are affected.

Percival[1] appears to have been the first to call serious attention to this disease. In 1902 he showed that the silvery appearance of the leaves was due, not to any change in the constitution of the chlorophyll, but to the formation of air-cavities in certain of the walls of the epidermal cells. He found that portions of roots of affected trees gave rise to the sporophores of *Stereum purpureum* when kept in a moist atmosphere. Upon inoculating branches of healthy trees with portions of these sporophores he found that the foliage of the inoculated branch subsequently became silvered. He concluded, therefore, that *Stereum purpureum* was the cause of the disease, and considered that this fungus secreted an enzyme which, upon being carried up the branch, produced the silvering of the foliage. More recently Spencer Pickering[2] has made a number of inoculation experiments with sporophores of this fungus, and in the large majority of cases silvering of the foliage of inoculated trees subsequently resulted. On the other hand, some observers doubt whether *Stereum purpureum* is the cause of the disease.

For the last two seasons I have been making observations and experiments on this disease among the fruit plantations of Cambridgeshire. The work is not yet complete, but the results which have so far come to hand are as follows :—

Large numbers of plum trees have been seen on the dead branches of which the sporophores of *Stereum purpureum* were present in abundance; in these

[1] Percival, *Journ. Linn. Soc.*, 1902, vol. xxxv.
[2] Spencer Pickering. Report of the Woburn Experimental Fruit Farm, 1906.

cases the foliage of the rest of the tree was silvered. On one of the red-currant bushes recently seen to be silvered the fruit bodies of this fungus were found to be growing. So far, the sporophores of *Stereum* have been found only on dead branches; upon cutting sections of these parts, hyphæ are found to be abundantly present in the vessels of the wood. No mycelium has yet been found in the portions of the silvered tree which are still living.

Certain inoculation experiments have been performed. In previous work on this disease all these experiments, as far as I am aware, have been made with pieces of the sporophores of *Stereum*. It was decided, therefore, to make a number of inoculations with clean spores, as well as a series of inoculations with sporophores.

Upon placing pieces of sporophore in the branches of healthy trees, the foliage beyond the point of inoculation became silvered a few months later. These results are identical with those of Percival and Pickering.

On the other hand, the spore inoculations have not yet resulted in causing the foliage to become silvered, although certain of these experiments were made more than a year ago. It is not likely that the germinative capacity of these spores was at fault because the spores have been found to germinate well in hanging-drop cultures of plum-wood extract. It is possible that the silvered effect may appear next season after the mycelium arising from the spores used in these inoculations has developed more luxuriantly. However, it is conceivable that the factor in the sporophore inoculations which causes silvering of the foliage to ensue may be absent from the spore inoculations.

In the course of this work it has been found possible to grow the mycelium of *Stereum purpureum* in pure culture. By sowing the spores on blocks of sterilised plum wood placed in suitable tubes, a good growth of mycelium has been obtained. It is proposed to use this mycelium in subsequent inoculation experiments. Derived as it is from pure cultures, none of the objections can be raised against the use of this mycelium that may possibly be urged against the employment of pieces of sporophores obtained from branches of diseased trees.

6. *An Arrangement for using the Wafer Blades of Safety Razors in the Microtome. By* B. H. BENTLEY, *M.A.*

FRIDAY, SEPTEMBER 2.

Joint Meeting with Section D.—See p. 628.

The following Papers were read in Section K :—

1. *Vegetative Mitosis in the Bean. By* Miss H. C. I. FRASER, *D.Sc., and* JOHN SNELL.

In the cource of an investigation of the nuclei of the root apex of *Vicia faba* it was observed that in the late telophase the chromosomes become attached laterally one to another. At the same time each chromosome was seen, especially in the region of these attachments, to be longitudinally split into two portions; the fission, widening more or less, was observed to persist throughout the so-called resting stages of the nucleus. Such an appearance of duplication has been recorded by various authors, and has been constantly explained as due to the approximation of paternal and maternal spiremes.

To obviate confusion from this source the study of gametophytic nuclei was undertaken, and it was found that in the mitotic divisions in the pollen-grain duplication of the chromosomes first appears in the late telophase; the formation of a reticulum is due to the lateral attachment and consequent pulling apart in places of the longitudinally split halves. On the formation of the spireme the lateral connections break down and the split halves become more or less closely

approximated, the spireme being double from its first formation till it divides into the longitudinally split chromosomes. On the spindle the longitudinal fission closes to reopen permanently as the daughter chromosomes travel to the poles.

The chromosomes therefore which separate one from another in any given division are the result of a longitudinal fission which is initiated in the preceding telophase, and the nucleus, alike of the sporophyte and gametophyte, shows a double structure throughout its resting stages.

2. *On the Somatic and Heterotype Mitoses in* Galtonia candicans. *By* Professor J. B. Farmer, *F.R.S., and* Miss L. Digby.

The question as to how the process of the reduction of chromosomes is effected is still unsettled. Two principal views are current:—

(1) That the reduction occurs during 'rest,' and that each meiotic division is associated with longitudinal fission as in a somatic division. This view implies the negation of chromosomal individuality.

(2) That meiosis is associated with a temporary pairing followed by the dissociation of somatic chromosomes, and their distribution to the daughter nuclei at either the first or second meiotic division. Further, that the temporary union is probably between homologous chromosomes derived from the male and female parent respectively. Amongst those who adhere to the latter interpretation of the process there is a difference of opinion as to the method by which the result of distribution of the chromosomes during the first meiotic division is achieved.

One school, represented prominently by the investigators at Louvain, believe that a side-to-side pairing at or before synapsis takes place, or that the chromosomes first issue from rest as paired structures (pro-chromosomes) and that there is nothing representing the longitudinal fission of the earlier and subsequent mitoses, but that the appearances which have been thus interpreted are illusory and depend on the approximation and subsequent divarication of distinct pairs of somatic chromosomes.

Another set of observers, including ourselves, consider that the appearance of early longitudinal fission is *not* illusory, but really corresponds to this process as met with in ordinary dividing nuclei. The union of entire pairs of chromosomes, whereby the reduced number is effected, is regarded as being due to an end-to-end union or non-separation, or else to be brought about by a pairing at 'second contraction.' We do not propose to go into the whole matter fully here; this has been done in a paper in course of publication. We wish, however, to draw special attention to certain facts, the general bearing of which seems to have attracted less attention than they deserve.

We refer to the results of a study of the complete series of events which intervene between telophase and prophase in the last archesporial, and the heterotype mitosis, together with the comparison between them and premeiotic divisions, whether in the archesporial or somatic tissues.

For purposes of illustration we have selected *Galtonia candicans*, mainly because it is specially favourable for this investigation, and also because it has been studied in part by others. We exhibit a series of drawings, as accurate as we could make them, to illustrate these most important stages, and we have also added one of a tapetal prophase.

It will be seen that in all of them, owing to the absence of 'resting' stages especially in the archesporial mitoses, there is a remarkable similarity, extending to minute details, between the prophase of the heterotype, the division in dispute, and the other and earlier mitoses in this plant.

As the telophase of an early archesporial division, for example, comes on, there is seen to be a condensation of the chromatin on the two edges of each of the chromosomes, and even when these have lost their early distinctness the duplicate character can still, and thus early, be detected. As the next division supervenes, again the dots or lines aggregate in pairs—the new chromosomal structures are longitudinally divided *ab initio*. The fission can be detected easily up to the spireme, and only becomes for the most part temporarily invisible as

the chromosomes thicken and reach maturity before their arrangement on the spindle. There the well-known fission reasserts itself, and results in the formation of the groups of chromosomes of the pair of daughter nuclei. Now, precisely similar conditions obtain during the early prophase of the *heterotype* mitosis in *Galtonia*. Neither in the somatic nor in the meiotic prophases is there a definitely numerical estimation of chromosomes possible: The number of separate chromatic structures is quite variable. The longitudinal fission in the heterotype is prepared for, as in the preceding mitoses, during the telophase of the last archesporial division, and on the reconstitution of the chromosomes in the early heterotype prophase, exactly similar paired arrangements are to be discerned as in a somatic mitosis. Finally the nucleus goes into synapsis; and here it must be admitted that it is not possible to follow exactly what occurs, but subsequent events show that at any rate there is at that stage no pairing of individual or homologous chromosomes. In the hollow spireme which follows, more or less definite traces of the preceding longitudinal fission can still be seen, and it may be mentioned in passing that there is some variation in the way in which the process as a whole is conducted. Sometimes the thread looks uniform, at other times threads made up of distinctly double filaments are to be seen. There is considerable anastomosis between the thread work at this stage, and the same is true of certain other plants in a still higher degree. Moreover, there is a considerable range of variation in the *thickness* of the threads—or thread-pairs—in the *same* nucleus. This is of weight, as much stress has been laid on thickness as a criterion of structure. A full account of these structural features will be published shortly. As second contraction comes on, the loops and tangles of the spireme become more closely appressed, and a paired arrangement quickly becomes obvious. The whole process is rapidly gone through, and there seems to be a wide range of variation in the actual manner of approximation. Thus sometimes a bending over of a loop, at other times the approximation of distinct chromosomes to each other takes place. There may be a twisting round each other or a merely parallel arrangement.

It is easier to follow out the process in *Galtonia* than in many other plants, owing to the remarkable difference of size which exists amongst the chromosomes themselves.

The later stages call for no particular comment, but we desire to call special attention to this plant as one in which there can be no mistake in the seriation. We have for some years selected *Galtonia* for detailed observation, owing to the advantage, already alluded to, of the absence of any intercalated phrase of 'rest' between the last archesporial and the heterotype mitosis. We feel convinced that the same interpretation to be placed on the events of prophase in the ordinary archesporial prophase, must also apply to the corresponding stage of the heterotype, and that, as was said some years ago, the union of somatic chromosomes to form the pseudochromosomes, and their separation at the heterotype mitosis, is to be regarded as a stage intercalated between the prophasic longitudinal fission of the heterotype and the completion of this fission, which is thus postponed to the homotype division. We would point out that those who hold the other view have never explained why there should invariably be *two* mitoses comprised in the meiotic phase.

3. *On the Vermiform Male Nuclei of Lilium.* *By* Professor V. H. BLACKMAN, *M.A.*

The shape and structure of these nuclei were described in detail, and circumstantial evidence brought forward that these structures, though purely nuclear in nature, are capable of movement, and make their way by their own activity into the egg-cell and towards the polar nuclei.

4. *Colour Inheritance in* Anagallis arvensis, *L.* *By* Professor F. E. WEISS, *D.Sc.*

The scarlet and blue pimpernels, regarded by some botanists as different species—*Anagallis arvensis*, L., and *A. cærulea* (Shreb) respectively are united

under the name *A. arvensis*, L., in the 'Index Kewensis,' and also in Engler's 'Pflanzenreich,' in which latter work they are given the varietal names of *phœnicea* and *cærulea*. The blue variety is stated to be without glandular hairs on the margin of the petals, but in all the specimens examined such hairs have been present, and the edge of the petals was not always markedly denticulate.

In both forms the throat of the corolla is of purple colour, due to the presence of a purple sap in the cells of this region, and in the centre of these purple cells there is always a collection of needle-shaped crystals of deep-blue colour. Sap of the same purple colour is found in the staminal hairs, and also in the glandular hairs which fringe the petals in both forms, but in the blue variety the basal cells of these glands contain numerous blue crystals similar to those found in the throat of the corolla. The sap of the cells appears to be acid, and, when treated with potash, the blue crystals observed in these cells are dissolved.

In the scarlet form the bright colour of the petals is due to a red sap, different in colour and in its chemical nature from the purple sap of the cells just referred to, at the base and the edge of the corolla. In the blue form the colour seems to be due to a blue sap, though possibly the appearance is really due to very finely divided particles of blue colour. When treated with dilute acetic acid the sap tends to become pink, and small blue granules make their appearance in the cells. Two other varieties of this species occur in nature, one somewhat salmon-coloured (*A. carnea* of Schrank) and one of pale-pink colour. Both these forms resemble the scarlet form, except in the lighter colour of their cell-sap, and have the same purple throat with blue crystals in its cells. Through the kindness of my friend Mr. Doeg, of Manchester, I obtained specimens of all four varieties from Anglesea, where they occur fairly commonly.

On pollinating the scarlet form with pollen of the blue variety I obtained plants which bore pure scarlet flowers, and the reciprocal cross, blue pollinated with pollen of a scarlet form, produced plants with scarlet flowers indistinguishable from the scarlet parent. Only on one or two flowers out of several hundred was a small blue streak noticeable on the petals and indicated the hybrid nature of the plant. The red colour was therefore dominant, and the blue colour recessive.

In the f_2 generation complete segregation took place, and the plants bore either brilliant scarlet or bright blue flowers; no intermediate colours were noticeable. This applied to the offspring from both of the crosses. No very good Mendelian ratios were obtained in the numbers of the blue and red plants, partly on account of the small number of the plants and partly owing to some interruption in the work. Up to the present the numbers in f_2 generation are—in descendants of *A. cærulea* ♀ × *phœnicea* ♂ sixty-two red and eight blue; in the case of the descendants of *A. phœnicea* ♀ × *cærulea* ♂ twenty-five red and two blue.

The pale-pink form was crossed with blue, and the latter colour was in this case also found to be recessive. The f_2 generation of this cross has not yet been obtained.

The complete dominance of the pure red colour in the crosses of the varieties *phœnicea* and *cærulea* is contrary to the suggestion which has been made (Engler's 'Pflanzenreich') that *A. carnea* (Schrank) is the hybrid of these two forms. It is more likely, I think, to be a pale variety of the scarlet pimpernel, especially as there is some difference in the depth of colour of this form. Experiments are now being carried on to settle this point.

The experiments described above confirm those of Focke ('Pflanzen-mischlinge,' 1881), who obtained a hybrid of *Anagallis arvensis-phœnicea* ♀ × *cærulea* in which the first flower had one-tenth of the corolla—*i.e.*, one-half of one petal—blue, while the rest was red, and all the subsequent flowers were red. He did not, however, carry his experiments on to the f_2 generation, and so did not observe the complete segregation of the two forms.

Gaertner, on the other hand ('Bastardenerzeugung,' 1849), states that the two forms do not produce fertile seed when crossed. In this connection it may be mentioned that a blue form sent me by Dr. Berger, of La Mortola, cannot be crossed with the ordinary red form. Other characters, too, seem to indicate that this Southern blue form may be a different species. The hybrid described by Dörfler

('Verh. der Zool.-bot. Gesel.' Wien, 1903) as *Anagallis arvensis×cærulea*, and which was considerably paler than *phœnicea*, may have been a hybrid of the paler form (*A. carnea*) with the blue pimpernel.

5. *Further Observations on Inheritance in* Primula sinensis.[1] *By* R. P. Gregory, *M.A.*

6. *Sand-dunes and Golf-links. By* Professor F. O. Bower, *F.R.S.*

MONDAY, SEPTEMBER 5.

Joint Discussion with Sections B and I on the Biochemistry of Respiration.

See p. 762.

The following Papers were read in Section K :—

1. *Note on* Ophioglossum palmatum. *By* Professor F. O. Bower, *F.R.S.*

It has already been shown that *Ophioglossum pendulum* and *simplex* (included in section *Ophioderma*) differ from others of the Ophioglossaceæ in the fact that the leaf-trace consists not of a single strand, but of more than one. It is true that in *Botrychium*, and less prominently in *Helminthostachys*, the single strand soon divides; but in both of these and in *Eu-ophioglossum* the leaf-supply is inserted as a single strand.

It was thought probable that *O. palmatum* (the only species of section *Cheiroglossa*) would share with the species above named the character of a divided trace, and material collected in Jamaica has shown that it does. The axis is much distended by parenchymatous storage tissue in pith and cortex, and as a consequence the meshes of the stele are transversely widened. From their margins right and left, but not quite simultaneously, arise two strap-shaped strands, which are thus widely apart in their origin. After subdivision into numerous smaller strands, these range themselves into two fan-like semicircles, which spread till their margins meet, forming the circle of strands of the petiole.[2]

A remarkable feature of the stock is the intrusion of roots into the bulky pith; this is especially obvious towards the base, where they pass out as thick mycorhizic roots.

Comparative study of leptosporangiate ferns has shown that the single strand is a primitive, and the divided strand a derivative, type of leaf-trace. If this hold also for the Ophioglossaceæ, then the section *Ophioderma* and *Cheiroglossa* are in this feature derivative as compared with the rest of the family. This conclusion is in accord with comparison on other grounds, whichever view be taken of the origin and affinities of the family—whether from early Filicales or from some such source as the Sphenophyllales. In either case their characters of external morphology indicate *O. pendulum*, *simplex*, and *palmatum* as extreme and specialised types,[3] and this estimate of them is now supported by the detail of insertion of the leaf-trace.

2. *On Two Synthetic Genera of Filicales.* By Professor F. O. Bower, *F.R.S.*

In a recent paper on the genus *Plagiogyria*[4] it has been shown that this type is certainly a substantive genus, quite distinct from *Lomaria*, with which it was

[1] Published in the *Journal of Genetics*, vol. i., p. 1, 1910.
[2] Compare *Annals of Botany*, vol. xviii., pl. xv., figs. 14, 18.
[3] *Ibid.* vol. xviii., p. 205, vol. xxii., p. 327.
[4] *Annals of Botany*, 1910, p. 423.

ranked by Sir W. Hooker, and that it occupies an important intermediate position, throwing light upon the phylogeny of certain ferns. Its stelar character, only slightly removed from solenostely, its undivided leaf-trace, its simple forked venation, occasional *dichotomy* of axis, absence of flattened scales, absence of a true indusium, its sorus initially simple but showing later a 'mixed' character, the segmentation of the sporangium, its thick stalk, oblique annulus, indeterminate stomium, and tetrahedral spores collectively indicate it as relatively primitive. It shows resemblances to all the great series of Simplices, but not to any one of them so clearly as to point to close affinity. Its position is probably in relation to the Gleicheniaceæ and Schizæaceæ, and perhaps specially to the latter. On the other hand, the 'mixed' character of the sorus, together with many of the features above named, points towards the Pterideæ. But these have a vertical annulus, while that of the *Plagiogyria* is oblique. This distinction is, however, bridged over by the fact that in *Cryptogramme* (with which *Plagiogyria* has been associated systematically by Diels[1]) traces of an oblique annulus are clearly seen. The sporangia are far from uniform in their details; the series of cells of the annulus may be at times irregular or broken; isolated cells of the wall may be indurated like cells of the annulus; sometimes the annulus may appear vertical and interrupted at the stalk, but at others it can be traced clearly past the insertion of the stalk. These facts indicate *Cryptogramme* as in an unstable condition between the oblique and the vertical annulus, and suggest that a real transition has occurred from the former as primitive to the latter as a derivative state.

If this be so, we have outlined a great phyletic sequence from some type of Simplices, allied in the neighbourhood of the Schizæaceæ and Gleicheniaceæ to the whole sequence of the Pterideæ, which have always been regarded as a relatively primitive series. And this transition appears to have been direct from the 'simple' to the 'mixed' sorus without any 'gradate' condition intervening.

Another somewhat similar sequence may be also recognised, but in this case leading to the 'gradate' series of Cyatheaceæ. It starts from the genus *Lophosoria*, represented by the single species *L. pruniata* (Pr.) designated by Christ *Alsophila quadripinnata* (Gmel.), C.Chr., and long merged in the genus *Alsophila*, from which it should be separated on various grounds. It is a low-growing tree-fern, with handsome leafage and profuse production of runners from the base of the stock. The young parts are covered by hairs, scales being absent. The stem shows solenostelic structure, especially in the runners, where the leaves are not crowded. The sorus is superficial and naked, of the Gleicheniaceous type, all the sporangia arising simultaneously; the annulus is oblique, but the dehiscence is lateral, and the spores approximately 64. Such characters point in the direction of *Gleichenia*, and especially to the more advanced types of *Mertensia*, such as *G. dichotoma* and *pectinata*. These, with *G. flabellata* as a relatively primitive species, form a sequence in which increase of anatomical complexity towards solenostely goes parallel with increase in number of sporangia in the sorus and decrease in size and spore-output of individual sporangia. There is, however, a decided break between the sporangial details in *Gleichenia* and those of *Lophosoria*. It is not suggested that *Lophosoria* is a further term in this series; but it is suggested that the mechanical possibilities of further elaboration of the sorus along the lines of *G. pectinata* with close-packed sporangia and median dehiscence were exhausted; that a new start was made by a race which, while maintaining the main characters of *Gleicheniaceæ*, adopted lateral dehiscence and finally a gradate sequence of sporangia; and that *Lophosoria* is perhaps the most primitive living example of that type.

On the other hand, the relation of *Lophosoria* to *Alsophila* is obvious; but *Alsophila* bears scales as well as hairs, though the sorus is naked. In *Hemitelia* the scales, in the form of an incomplete indusium, imperfectly protect the sorus, while in *Cyathea* the specialisation of the scale for this purpose is perfected in the indusium. Such protection became all the more necessary as the 'gradate' development was assumed.

It would further appear, if this sequence is correct, that the prostrate position

[1] Engler and Prantl. *Pflanzenfam.*, I., 4, p. 279.

was probably represented in the earlier terms of this series, and that the upright position of the more advanced Cyatheaceæ was a secondary condition.

Thus, by the help of the two synthetic genera above named, it becomes possible to trace the origin of two great sequences of living ferns along lines more or less parallel but distinct: the one leading to a multiplicity of 'mixed' types represented by the Pterideæ, the other to some of the most prominent 'gradate' types of the Cyatheaceous affinity. And it appears that these may both have arisen from types of the 'Simplices' having affinities with the Schizæaceæ and Gleicheniaceæ.

3. *On the Fossil genus* Tempskya. *By* R. Kidston, *LL.D., F.R.S., and* D. T. Gwynne-Vaughan, *M.A.*

From the examination of some specially well-preserved Russian petrifactions belonging to this genus it may be safely stated that these fossils consist of aggregates of branching fern stems imbedded in a compact mass of their own interwoven adventitious roots.

The 'false stems' thus produced no doubt grew erect as columnar or conical structures, attaining a height of nine feet or more. The individual stems are only about the thickness of a slate pencil, and they possess a solenostelic vascular system. Strange to say, although growing erect, they exhibit a well-marked dorsiventral symmetry, with the leaves all on one side of the stem and adventitious roots on the other.

The existence of a fern possessing this peculiar habit of growth opens the way to the suggestion that the strong, erect, arboreal stems of the modern tree-ferns may not be a primitive feature of the order. These plants may have been derived from forms with a Tempskya-like habit, in which the original axis has so greatly surpassed its branches in size and importance that the latter are now almost entirely suppressed. As a result we have now a single main axis strong enough to grow erect without the additional support of a root coating.

4. *Further Observations on the Fossil Flower. By* Miss M. C. Stopes, *D.Sc., Ph.D.*

The ovary and perianth of a petrified flower (*Cretovarium japonicum*, Stopes and Fujii) from the Cretaceous rocks of Japan were recently discovered by Professor Fujii and the author. The specimens were petrified in concretionary nodules, and show the cell structure, but did not contain ovules.

Another specimen has now been discovered, in which the ovary wall is much better preserved, showing an outer fleshy layer as well as the sclerosed layer, and also containing several ovules.

5. *The Morphology of the Ovule of* Gnetum africanum. *By* Mrs. M. G. Thoday.

In the young ovule the three coverings arise together at the base of the nucellus, and the greater portion of the nucellus stands free in the centre of the ovule. During later development the region between the two inner coverings becomes more and more stretched, so that the innermost covering arises near the apex of the nucellus, and the free portion of the nucellus in the mature seed is very small in proportion to the part developed by intercalary growth.

The outer covering resembles the bracts in structure, and is here regarded as an extra covering, while the two inner are called integuments, and are compared with the two integuments in *Welwitschia*. The middle covering or outer integument has a well-developed vascular supply and is traversed by numerous strands of fibres reduced higher up to four or five. At the tip the outer integument firmly clasps the micropylar tube, and a transverse section at this level shows the four or five strands forming a star of strongly lignified tissue.

The inner integument is formed of thin walled tissue, and in the young ovule strands of meristem run up into it for some distance above the base; when the

xylem of the lower portions of these strands is lignified the lignification seldom extends beyond the base of the integument, but sometimes one or more spirally thickened tracheids are found running up into it. The tip of the inner integument forms the micropylar tube, traversed by a slit-like micropyle; there is an external ridge-like outgrowth from the tube which turns back and fits tightly over the top of the middle covering.

The embryo sac is developed between the levels of origin of the two inner coverings and grows as the intervening region stretches. It projects into the free portion of the nucellus. A well-developed pollen chamber is present in the young ovule. As it decays the nucellar tissue below it becomes lignified and forms a hard beak.

The radial structure of the seed, the presence of a pollen chamber, and the small development of the free portion of the nucellus are all points of striking contrast to *Welwitschia*, and probably point to the more primitive character of the *Gnetum* ovule. The two integuments in both seeds are compared with the two integuments of *Lagenostoma*, the vascular system of the inner integument having suffered considerable reduction.

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6. *On the Diversity of Structures termed Pollen-Chambers.* *By* Professor F. W. Oliver, *F.R.S.*

The object of this paper was to show that in several of the lesser-known fossil-seeds of Coal Measure times (*Conostoma oblongum*, *C. anglo-germanicum*, and perhaps *Gnetopsis*), belonging in all probability to the Lyginodendreae section of Pteridosperms, the structure of the nucellar apex was much more complex than in either *Lagenostoma* or *Physostoma*. This elaboration arose through the excavation of the plinth below the ordinary pollen-chamber, so that a second chamber was provided into which the pollen was received and in which it doubtless matured the male gametes. The upper chamber, evidently homologous with the pollen-chamber of *Lagenostoma*, is thus vestigial in character. The pollen-chambers of *Trigonocarpus* and other seeds attributed to the Medullosae section of Pteridosperms, and also those of Ginkgo and recent Cycads, were considered from this point of view, and the suggestion was made that perhaps the nucellar beak might also be a vestigial primary pollen-chamber which had become functionally replaced by a deeper-seated cavity, in which the pollen grains pursued their further development.

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7. *On the Stock of Isoëtes.* *By* Professor William H. Lang, *D.Sc.*

A re-examination of the anatomy of the stock of *Isoëtes* has confirmed the view of Von Mohl that the roots are borne in regular order on a downwardly growing region. The root-bearing region of the stele is not due to secondary modification of the base of the leaf-bearing portion, but is, from the first, a distinct region.

The apex of the stem is well known to be seated in a deep depression, and the so-called secondary growth of the cortex is required to carry out the leaves from the central region and thus leave room for new leaves to arise. The basal root-bearing region of the plant corresponds to such a depressed apex with the root-bearing surfaces facing one another and congenitally united. The grooves separating the lobes of the stock come apart by the separation of these united surfaces, and this continued process of splitting brings the young roots to a free surface.

While greatly modified by the slow and stunted growth of both the leaf-bearing and root-bearing regions of the stock, the whole axis of the *Isoëtes* plant can be compared with that of *Lepidodendron* or *Pleuromeia*. The root-bearing region appears to be strictly comparable with the Stigmarian base of these plants. Such a comparison, though neglected of late years, was made by Williamson in his monograph on *Stigmaria*.

TUESDAY, SEPTEMBER 6.

The following Papers were read :—

1. *The Paths of Translocation of Sugars from Green Leaves.* *By* S. MANGHAM, *B.A.*

The primary object of this research, undertaken at the suggestion of Mr. A. G. Tansley, is the reinvestigation of the paths taken by the sugars during the translocation from the leaves of green plants. Haberlandt,[1] from anatomical considerations, and Schimper,[2] from the results of microchemical investigations, concluded that the sugars travel in the parenchymatous bundle sheaths of the leaf veins—the 'conducting sheaths.' Czapek,[3] however, put forward the theory that while diffusion goes on in all living parenchymatous cells, yet for comparatively rapid translocation over long distances the sieve tubes furnish the sole paths for the assimilates as a whole. Haberlandt[4] considered Czapek's evidence insufficient to warrant his conclusions, and attached greater importance to Schimper's experiments.

Both Czapek and Schimper employed Fehling's solution as a test for reducing sugars, a method open to the objections that the reagent is reduced by organic substances other than sugars present in the plant, that a good deal of diffusion of cell contents goes on in the hot aqueous solution, and that the small granules of copper oxide precipitated are not always easy to observe.

A very much better sugar test is to be found in the precipitation of yellow osazones in the manner introduced by Senft.[5] Using this method I have secured photomicrographs showing the distribution of osazones after the tissues had been subjected to known experimental conditions. Long longitudinal sections of veins, cut and examined after darkening leaves for suitable periods, showed the distal ends free from osazones. Further down these appeared, as soon in the sieve tubes as in the surrounding parenchyma, while near the base the sieve tubes stood out clearly, on account of the abundance of the contained osazones. Experiments with pure sugar solutions have shown that to some extent it is possible to distinguish between sugars, and the method is accordingly being used to study the changes undergone by carbohydrates in darkness.

The results so far obtained indicate (1) that the sieve tubes provide the main paths for the removal of free sugars from the lamina, and (2) that both monoses and bioses travel in the sieve tubes.

Some results suggest that there is a periodicity in the translocation of free sugars, and this point is undergoing further investigation. The work is in course of extension to the gymnosperms and lower vascular plants, and it is hoped later on to examine the sieve tubes of some of the larger algæ by means of the same sugar test.

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2. *Assimilation and Translocation under Natural Conditions.* *By* D. THODAY, *M.A.*

Detached leaves of *Helianthus annuus* in very bright diffuse light were found to increase in dry weight at the comparatively low rate of 6 mg. per square decim. per hour, whereas in bright sunshine, even under a canvas screen, the rate previously observed had been 17 mg.

Attached leaves showed a smaller rate of increase than detached leaves, but the difference was less in diffuse light than in sunshine, and in dull light practically nil. The full explanation of these facts is still to be sought, but translocation is probably the prime factor concerned: in one experiment a detached leaf which was rather limp increased in dry weight as rapidly as attached leaves, which gave readings with the horn hygroscope three or four times as high.

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[1] *Pringsh. Jahrb.*, 1882.
[2] *Bot. Zeit.*, 1885.
[3] *Sitz. Akad. Wien*, 1897.
[4] *Physiologische Pflanzenanatomie*, 1904, p. 350.
[5] *Sitz. Akad. Wien*, 1904.

3. *On a New Method of Observing Stomata.* *By* FRANCIS DARWIN, *D.Sc.*, *F.R.S.*

4. *Germination Conditions and the Vitality of Seeds.* *By* MISS N. DARWIN *and* DR. F. F. BLACKMAN, *F.R.S.*

5. *The Absorption of Water by certain Leguminous Seeds.* *By* A. S. HORNE, *B.Sc.*, *F.G.S.*

This paper dealt with some of the problems connected with the swelling of cultivated leguminous seeds under different experimental conditions in the light of a knowledge of their anatomy. The trough-like organ figured by Nobbe in 'Handbuch der Samenkunde' is a secondary development, at least, in the lupine, and, although apparently adapted for the admission of water, did not function in this capacity under the circumstances of the experiments described. The shape of the trough is a distinctive character in certain peas used by Mr. A. D. Darbishire for breeding experiments—*e.g.*, the bean pea, Express pea, &c.

In each experiment a number of single seeds was used, and weights and volumes, or both weights and volumes, determined over short intervals of time for continuous periods of twenty-four hours or more, so that the behaviour of each seed could be represented by a curve. The curves obtained for submerged seeds with closed micropyle in some genera—*e.g.*, *Vicia Faba*—differ considerably from the curves for unsealed seeds. The use of the micropyle, however, for the admission of water would probably not occur normally in Nature. In every case, directly the seed commenced to absorb, water entered continuously through the seed-coat. Distinctive curve-forms have been obtained for different varieties of the lupine—*e.g.*, white, yellow, and blue—and for Mendelian peas—*e.g.*, round and wrinkled peas, the bean pea and Express.

The results obtained by keeping absorbing seeds at different temperatures were complex, the variability depending upon different combinations of variable factors, such as the use of the micropyle, the properties of the seed-coat, and the behaviour of the embryo. The data resulting from experiments of this kind may be conveniently represented by means of dot diagrams, wherein each dot corresponds to a definite increase in weight per hour.

In order to compare the behaviour of certain seed-coat membranes—*e.g.*, broad bean, scarlet-runner bean, white Dutch runner bean—and other membranes with respect to osmotically active solutions, numbers of seed-coat osmometers were made. Seed-coats of the white Dutch runner bean proved highly satisfactory, the column of liquid rising in the tube against a small initial pressure upon the seed-coat in five days to a higher level than it did in the case of the pig's bladder membrane in seven or eight days under similar conditions.

These experiments were carried out with the assistance of Miss S. Coull, B.Sc., and Mr. J. W. Holzapfel, B.Sc.

WEDNESDAY, SEPTEMBER 7.

The following Papers and Reports were read :—

1. *The Association of certain Endophytic Cyanophyceæ and Nitrogen-fixing Bacteria.* *By* Professor W. B. BOTTOMLEY, *M.A.*

Recent investigation of the root-tubercles of Cycas[1] has demonstrated that the nitrogen-fixing bacteria Pseudomonas and Azotobacter are always found in association with Anabæna in the algal zone of the root-tubercles. Examination of

[1] *Proc. Roy. Soc.*, B., vol. viii., p. 287.

the Anabæna spaces of Azolla leaves, and the Nostoc cavities in Anthoceros thallus shows a similar association of the alga with nitrogen-fixing bacteria in these plants. In thin microtome preparations fixed with Bonin's fixative, and stained with Kiskalt's amyl grain-stain both Azotobacter and Pseudomonas can be readily identified among the algal threads. A mixed culture of the two organisms can be obtained by crushing some Azolla leaves or Anthoceros thallus on a slide in distilled water under sterile conditions, inoculating a solution consisting of water, 100 c.c.; mannite, 1 grm.; maltose, 1 grm.; potassium phosphate, 0·5 grm.; and magnesium sulphate, 0·02 grm.; and incubating at 24° C. for two days. Microscopical examination with Kiskalt's amyl grain-stain and Ziel's carbol fuchsin shows the culture to be a mixture of Pseudomonas and Azotobacter.

Agar plates made by adding 1 grm. of agar-agar to the above nutrient solution, and inoculated with a few drops of crushed Azolla leaves or Anthoceros thallus, gave in two days the typical round colonies of Azotobacter and ovoid colonies of Pseudomonas. It is possible that this association is advantageous to the host plant—the alga supplying the necessary carbohydrate for the nitrogen-fixing bacteria, and the host plant absorbing some of the nitrogenous product.

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2. *Notes on the Distribution of Halophytes on the Severn Shore.* *By* J. H. Priestley, *B.Sc., F.L.S.*

These notes are the result of a detailed study of a small area on the left bank of the Severn between Lyttelton Worth in Gloucestershire and Burnham in Somerset. They refer more especially to the pelophilous formations in this area. Analyses have been made of the salt content and water content of the soils from representative spots within the area, and as a result it has been possible to draw certain conclusions as to the connection between drainage and plant zonation. The plant distribution within the zones showed certain anomalies, but these can probably be explained by reference to the soil analyses.

The general adaptation of the plants of the pelophilous zone to their habitat is discussed, and it is suggested that this formation is disappearing somewhat rapidly from most parts of this coast.

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3. *Plant Distribution in the Woods of North-East Kent.* By Malcolm Wilson, *B.Sc.*

In this district a large proportion of the woods is coppice with standards, felling taking place about every fourteen years. There is little variation in the altitude, and the plant distribution depends chiefly on the character of the soil.

The following can be distinguished :—

1. Beech type on the shallow soils of the chalk. The standards are chiefly beech, the undershrubs consisting of yew, oak, hazel, *Cornus sanguineus, Euonymus europœus,* and *Ligustrum vulgare. Viola hirta, Verbascum Thapsus, Euphorbia amygdaloides,* and *Mercurialis perennis* are abundant.

2. Ash-hazel type on the 'clay with flints' on the chalk. Hornbeam is frequently found; oak standards are usually present. *Mercurialis perennis* is abundant, with *Primula vulgaris* and *Scilla nutans.*

3. Chestnut type on the Thanet sand; usually coppice with chestnut or oak standards. *Rubus fruticosus* is often present. On the deeper deposits *Scilla nutans* is abundant, with *Lychnis diurna* and *Adoxa Moschatellina. Asperula odorata* and *Solidago Virgaurea* are characteristic of this formation.

4. Oak-birch-heather type on the Woolwich and Reading series and on the Oldhaven pebble beds. *Pinus sylvestris* is frequently found here. The woods are usually thin and open; heather and bracken are abundant, with *Luzula pilosa* and *Rumex Acetosella.* The soil is usually strongly acid.

5. Oak type on the London clay; usually coppice with oak standards. Bracken is abundant, and many plants found in woods of the preceding type occur. There is usually a sharp distinction between the woods occurring on the calcareous soils and those on the tertiary formations. In the former the soil acidity is slight or none, and *Mercurialis perennis* is abundant; in the latter the soil is acid, and

Mercurialis perennis is absent. Woods of intermediate character are found on alluvial deposits and on the edges of tertiary deposits.

On the 'clay with flints' the distribution is closely connected with the depth of the deposit, and as a result definite zonation frequently occurs. Analyses to determine (i) the percentage of lime, (ii) the acidity, and (iii) the water content in soils of varying depths are being performed.

Observations have also been made on the distribution of the commoner mosses.

During the latter years of the coppice growth a deep shade is produced and few herbaceous plants occur. Those found can be grouped as : (1) plants little or not affected by the shade, which usually flower early in the spring; (2) dwarf plants which persist in the vegetative state and rarely flower.

During this period there is an increase in the amount of humus, probably a simultaneous increase in acidity. Analyses are now being made to determine these points.

Felling causes a great increase in the light intensity, and the temperature of the surface soil is increased. These changes result in a great increase in the number of herbaceous plants. These may be divided into : (1) plants which have persisted during the shade period, and many of which now develop luxuriantly; (2) woodland plants unable to exist in the shade period. These are largely biennial, but a few annuals and perennials are found.

The maximum development of herbaceous plants is reached during the third year. After this they gradually diminish, on account of the increase of shade. The shade condition of the vegetation is reached by about the tenth year.

4. *Report on the Survey of Clare Island.*—See Reports, p. 301.

5. *Report on the Experimental Study of Heredity.*—See Reports, p. 300.

6. *Report on the Structure of Fossil Plants.*—See Reports, p. 301.

Section L.—EDUCATIONAL SCIENCE.

President of the Section.—Principal H. A. Miers, M.A., F.R.S.

THURSDAY, SEPTEMBER 1.

The President delivered the following Address:—

To preside over this Section is to incur a responsibility which I confess somewhat alarms me; for the President may, by virtue of his temporary office, be regarded as speaking with authority on the subjects with which he deals. Now, it is my desire to speak about University education, and for this purpose I must say something of school education; but I would have it understood that I really know little about the actual conduct of modern school teaching. One may read books which describe how it should be conducted, but this is a very different thing from seeing and hearing the teacher in his class; and I fear that personal recollections of what teaching in preparatory and public schools was like from thirty to forty years ago do not qualify one to pose as an intelligent critic of the methods which now prevail.

Human nature, however, has not changed much in the last forty years, and if, in considering the relations between University and school education, I can confine myself to general principles, based upon the difference between boys and men, I trust that I may not go far wrong.

I propose first to consider some general relations between teachers and their pupils, and then explain what, in my opinion, should be the change in the method of teaching, or at any rate in the attitude of teacher to pupil, which should take place when the scene changes from school to University.

First as to general relations between teachers and their pupils.

Educational systems necessarily prescribe the same methods for different teachers, and, being made for the mass, ignore the individual. But happily, in spite of the attempts to formulate methods of instruction and to make precise systems, there are many, and those perhaps some of the most successful, in the army of earnest school teachers who are elaborating their own methods.

Now among all the changes and varieties of system and curriculum there is one factor which remains permanent and which is universally confessed to be of paramount importance—the individuality of the teacher and his personal influence upon the pupil. It is therefore a healthy sign when school teachers who have been trained on one system begin to develop their own methods, for in this they are asserting their individuality and strengthening that personal influence which is the real mainspring of all successful education.

Personal influence is, of course, not only a matter of intellectual attainments; it appears to me, however, that at the present time so much is made of the duty of schools to aim at the formation of character that there is an unfortunate tendency to regard this duty as something distinct from the other functions of a master, and as independent of intellectual qualifications. Among the first qualities now demanded of a master in a public school for boys are manliness, athletic skill, and a hearty and healthy personality, and these are often regarded as compensating for some lack of intellectual equipment. I suspect that there is a similar tendency in schools for girls. And yet I think it will be found that the only permanent personal influence is really wielded by teachers who exercise

it through intellectual channels, and that those who acquire intellectual authority will generally succeed in training the characters as well as the minds of their pupils.

On the other hand, the master who is not up to the proper intellectual standard will soon be found out by his cleverer pupils, and will lose influence, whatever may be the charm of his character.

The formation of character, so far as it can be distinguished from intellectual training, is largely worked out by the boys themselves in any public school in which healthy tradition and a sound moral atmosphere are maintained, although it is true that these traditions depend upon the character and personality of the teachers.

The educational value of the personal and intimate association with one and the same teacher throughout the school or University career is officially recognised in the tutorial system at Eton, Oxford, and Cambridge. It has generally led to excellent results, provided that the tutor possesses the right qualities and that pupil and tutor do not happen to be two incompatible personalities; but the results may be well-nigh disastrous where there happens to be antagonism between the two, or where the tutor does not realise his opportunities and responsibilities. I have known some tutors who only excited a distaste for learning in their pupils, and others who entirely neglected or abused the high trust which had been committed to them; but far more, I am glad to say, who have not only exercised the most profound influence for good on their better and cleverer pupils, but also inspired intellectual interest in the most unpromising of them. Although such a tutorial system does not enter fully into the scheme of other schools and Universities, and therefore a student does not usually remain long under any one teacher, it must be within the experience of most persons to have come for a time at least under the influence of a teacher who has inspired real enthusiasm for learning and from whose lips the instruction, that might from others have been a trial, has become an intellectual treat.

It is given to comparatively few to exert this powerful and subtle influence in a high degree, for it is a gift confined to a few rare natures. All the more important is it, therefore, to ensure that an effective personal influence may play its part in the intercourse between ordinary teachers and ordinary pupils in the customary routine of school and University life.

How, then, is the proper personal and sympathetic relation to be established between teacher and pupil, so that the individuality of the one may call out the character and the effort of the other? Those who enquire of their earliest school reminiscences will probably recollect that the teachers who obtained a real hold upon them did so by virtue of the power which they possessed of arousing their intellectual interest. I would ask you for a moment to analyse the character of this interest.

In the young child I believe that it will be found to be mainly that of novelty: with him 'this way and that dividing the swift mind,' sustained thought, or even sustained attention, has not yet become possible; the inquisitive and acquisitive faculties are strong; and every new impression awakens the interest by its novelty quite apart from its purpose. You have only to watch and see how impossible it is for a young child to keep its attention fixed even upon a game such as cricket or football to realise how still more difficult it is to keep his attention fixed upon an intellectual purpose.

To quite young children, except to those who are unfortunately precocious, even an impending examination is not a permanent object of anxiety.

Now contrast the aimless interest which can be aroused in any young child's mind by the pleasure of a new impression, a new activity, or a new idea, with that which appeals, or should appeal, to the more mature intellect of an older student. With him it is not enough that the impression or the idea should be new; if it is to arouse interest it must also direct his mind to a purpose. This is to him the effective interest of his games or sport; in the game the desire to succeed or to win is the animating purpose, just as the expectation of catching a fish is the interest which keeps the angler's attention fixed for hours upon his line. In both the desire is fostered by the imagination, which maintains a definite purpose before the mind.

It is sometimes forgotten that as he grows the pupil is no longer 'an infant crying for the light,' but has become a man with 'splendid purpose in his eyes.'

While, therefore, it should be the aim of a teacher of young children to set before them the subjects of their lessons in an attractive manner, so that the novelty is never lost, and not to weary their active and restless minds with too sustained an effort, it should at a later stage be the teacher's aim to keep the object and purpose of the new fact or idea as constantly as possible in view, and not to distract the ardent mind with purposeless and disconnected scraps of learning.

I ask you to bear this distinction in mind, for it is a principle which may guide us in differentiating University methods from school methods of education.

The distinction need not involve us in a discussion of the 'Ziel-Angabe' in elementary education, for that is rather a question of keeping the interest alive during each lesson than of maintaining a permanent purpose in view throughout a course.

The much discussed Heuristic method as applied to very young children does, no doubt, fulfil this object so far as it provides the inquisitive mind with novelty instead of a set task, but so far as it makes the purpose more prominent than the process it may become a method more suited to the adolescent or the adult mind than to that of the young child.

I can fully realise that a most difficult and anxious time for the teacher must be that of the maturing intellect, in the interval between childhood and the close of the school career, when the method and spirit of the teaching must to some extent gradually change with the changing mental characteristics of the pupil. But, whatever may be the right methods of teaching children of ten and young men and women of twenty, many of our failures are due to one or both of two prevalent mistakes: the first, the mistake of teaching children by methods that are too advanced; the second, that of teaching University students by methods that are better adapted for school children. It is with the latter that I wish to deal in this address; but we may in passing remind ourselves that when young men and young women are sent straight from the University to teach children with nothing but their University experience to guide them, it is not surprising that they often proceed at first on wrong lines and as though they were dealing with University students.

The difficulty of divesting oneself of the mental attitude and the form of expression familiar in University circles, if one is to become intelligible even to the higher classes in a school, is betrayed by the unsatisfactory nature of many of the papers set by University examiners to school children. The teachers complain, and rightly complain, that there is often an academic style and form about them which just make them entirely unsuitable for the child.

It is, of course, hopeful that a diploma in pedagogy or some evidence that they have received instruction in method is now generally required of those who are to become teachers in schools. It seems to me, however, somewhat curious that, while efforts are now being made to give instruction in educational method to such persons, no similar effort is made to give instruction in more advanced methods to those who are called upon at the close of their undergraduate career to become University teachers, and that in consequence many of them have no method at all.

This may be a matter of comparatively small importance to those who possess not only the necessary knowledge, but also the natural gift of personal influence and the power of inspiring those whom they teach. But for those who are not blessed with these powers it may be almost as difficult to fall into the ways of successful University instruction after the sudden transformation from student into teacher as it is for those who become teachers in schools.

Granting, then, that there should be a radical difference between the ways of school and University teaching, and that there is at present an unfortunate overlapping between the two, let me next consider how the distinction between the intellectual interest of a child and the intellectual interest of a man may guide us in adjusting our methods of teaching when students pass from school to the University.

A tenable, perhaps even a prevalent, view concerning a liberal school education is that its chief purpose is not so much to impart knowledge as to train the mind; indeed, some teachers, influenced, perhaps, in the first instance by the views of Plato, go so far as to think that no subject which is clearly of direct practical

use should be taught as such at school. This view they would carry to the extent of excluding many obviously appropriate subjects from the school curriculum, whereas almost any subject may be made an intellectual training; this being a question not of subject, but of the manner in which it is taught. In any event, if the scheme of intellectual training be adequately fulfilled, the period of mental discipline should come to an end with the close of school life, and the mind should then be able to enter upon new studies and to assimilate fresh knowledge without a prolonged continuation of preparatory courses. Indeed, the professed object of entrance examinations to the University is to exclude those whose minds are not prepared to benefit by a course of University study, and to admit only those who are sufficiently equipped by previous training to do so. An entrance examination then should not be merely a test of whether a boy or girl has learnt sufficient of certain subjects to continue those subjects in particular at the University; and yet it has unfortunately come to be regarded more and more as performing this function instead of being regarded as a test whether the student is generally fit to enter upon *any* University course. The result is that an entrance examination tends to become a test of knowledge rather than a test of general intelligence; merely one in an organised series of examinations which endeavour to ascertain the advancing proficiency in a limited number of subjects, and therefore tend really to encourage specialisation. Specialisation is not to be prevented by insisting on a considerable number of subjects, but rather by teaching even one subject in a wide spirit. Another result is that the entrance examination belongs properly neither to the school course nor to the University course; if it is taken at the age of sixteen the remainder of the school career tends to be devoted to University work, which should not really be done at school; if it is taken after leaving school this means that work is being done at, or in connection with, the University which ought to be done at school. It is certainly true that for various reasons a vast deal of education is now being carried on at the Universities which should belong to school life, and moreover is being carried on by methods which are identical with those pursued at school. It is equally true that, owing to the early age at which matriculation examinations or their equivalents may be taken, many schools are now asking that at the age of eighteen or nineteen a school examination may be held which shall be an equivalent not for matriculation, but for the first degree examination at the University. This would really imply that schools should be recognised as doing University work for two years of their pupils' careers—surely a most illogical procedure and one which supports my contention that there is now very serious overlapping, for it assumes that the work for the first degree examination can be carried on either at the school or the University, and therefore that there is no difference in the methods of the two.

An increasing number of candidates actually present themselves from secondary schools for the external intermediate examination of the University of London; in 1904 there were about 150, in 1909 there were nearly 500 such candidates.

There will always be exceptional boys and girls who reach a University standard, both of attainments and intelligence, long before they arrive at the ordinary school-leaving age. Let them either leave school and begin their University career early, or let them, if they remain at school, widen their knowledge by including subjects which are not supplied by the more rigid school curriculum designed for the average pupils; but let them not cease to be taught as school pupils. It is equally certain that there will also be boys and girls whose development is so slow that they barely reach the University standard when they leave school; yet some among them are the best possible material and achieve the greatest success in the end. For such persons an entrance examination will be required at the age of eighteen or nineteen; but I think it is unfortunate that this should be the same as that which quicker pupils can pass at the age of sixteen or seventeen, for an examination designed for the one age can scarcely be quite satisfactory for the other.

I confess that the whole matter is inextricably involved with the question of University entrance examinations. But to enter upon this here would carry us beyond the limits that I have laid down for myself, and it will be more profitable to decide what should be done at school and the University respectively before discussing how the examinations are to be adapted to our purpose. It will be sufficient for me to say that I have been led to the conclusion that matriculation

examinations should be designed to suit the capacity of average pupils not less than seventeen years of age, if they are to test the intelligence of those who are ready to enter upon a University course.

Starting, then, with the principle that the period of mental discipline is closed at the end of the school career, and that those who pass to the University come with fair mental training and sufficient intelligence, let me inquire what should be the relation of University teaching to that which the student has received at school.

Under present conditions the schools which aim at sending students to the Universities endeavour to give a general education which will fit their pupils to enter either upon a University course or upon whatever profession or occupation they may select on leaving school. They do not confine the teaching of any pupil to preparation for a special profession or occupation, and they do not generally encourage special preparation for the University.

Now contrast what happens to the pupils leaving such a school to enter a profession or business with what happens to those who proceed to the University. The former pass into an entirely different atmosphere; they are no longer occupied with exercises and preparatory courses which serve a disciplinary purpose; they are brought face to face with the realities of their business or profession, and, though they have to gain their experience by beginning at the lower or more elementary stages, they do actually and at once take part in it.

The University student, on the other hand, too often continues what he did at school; he may attend lectures instead of the school class, but neither the method nor the material need differ much from what he has already done. Should not the break with school be as complete for him as for his school-fellow who goes into business? Should he not be brought face to face with the actualities of learning? After his years of preparation and mental drill at school should he not, under the direction of his University teachers, appreciate the purpose of his work and share the responsibility of it?

Let me take, as an illustration, the subject of History. A public school boy who comes to the University and takes up the study of history should learn at once how to use the original sources. It will, of course, be easier for him if he has learnt the rudiments of history and become interested in the subject at school; but, if he is really keen upon his University work, it should not be absolutely necessary for him to have learnt any history whatever. In any case, if he has received a good general education and has reached the standard of intelligence required for University work, he ought to be able to enter at once upon the intelligent study of history at first-hand; his teachers will make it their duty to show him how to do this; their lectures and seminars will illustrate the methods of independent study, and will make the need of them clear to him. If, as is probable, some acquaintance with one or more foreign languages be necessary, he will take instruction in them as an essential part of his history course, in order that he may acquire the needful working knowledge; and to learn something of them with a definite purpose will be to him far more interesting and profitable than to study them only for linguistic training, as he would have been compelled to do at school. After all this is what would be done by his school-fellow who goes into business and finds it necessary, and probably also interesting, to acquire some knowledge of the particular foreign language required in the correspondence of his firm. It will, of course, be all the better for a University student of history to have acquired some training at school in the rudiments of history both ancient and modern, together with the knowledge of classics which is necessary for the former, and of modern languages which is necessary for the latter. But there is not space in the school curriculum for all the subjects that may be required either for the University or for the business of life; the best that can be done is to give a good all-round training and to foster a marked taste or ability where it exists by allowing the boy or girl to include the subjects which are most congenial to them in the studies of their last two years of school life, as I have already suggested, provided that mere specialisation is not encouraged at school even towards the end of the school career.

The University course might then become a more complete specialisation, but of a broad character—the study of a special subject in its wider aspects, and with the help of all the other knowledge which may be necessary to that purpose.

The University teacher will also differ from the school teacher in his methods, for it will be his business not so much to teach history as to teach his pupil so to learn and study history as though it were his purpose to become an historian; in so doing he will have opportunities to explain his own views and to contrast them with those of other authorities, and so to express his individuality as a University teacher should.

One might choose any other subject as an illustration. In science there should be all the difference between the school exercises, on the one hand, which teach the pupil the methods of experiment, illustrate the principles laid down in his text-books, and exercise his mind in scientific reasoning, and, on the other hand, the University training, which sets him on a course involving the methods of the classical researches of great investigators and a study of the original papers in which they are contained, illuminated by the views of his own teacher. He also should awaken to the necessity of modern languages. A boy who, on leaving school, passes not to the scientific laboratories of a University, but to a scientific assistantship in a business or Government department, will very soon find it necessary to go to the original sources and acquire a working knowledge of foreign languages. It is regrettable that under existing conditions a scientific student sometimes passes through his University without acquiring even this necessary equipment. I believe this to be largely due to the fact that he is compelled to spend so much of his time in preparatory work of a school character during the early stages of his University career.

In the literary subjects, and especially in classics, there is, of course, not the same scope for the spirit of investigation which it is so easy to encourage in experimental science. Here the only new advances and discoveries which can appeal to the imagination in quite the same way are those which are being made every year in the field of archæology, and it is therefore not surprising that this subject attracts many of the most ardent students: the methods of the archæologist are more akin to those of the scientific investigator, and his work is accompanied by the same enthralling excitement of possible discovery. For the more able pupils and those who had a natural taste for language and literature no subjects have been more thoroughly and systematically taught for very many years at school, as well as at the University, than the classics; but for the less intellectual children or those who had no natural taste for such studies no methods could well be more unsuitable than those which used to prevail at schools. The grammatical rules and exceptions, the unintelligent and uncouth translation, the dry comparison of parallel passages, the mechanical construction of Greek and Latin verse, produced in many minds nothing but distaste for the finest literature that exists.

With the improved methods now in use Greek and Latin may be, and are, presented to the ordinary boy and girl as living literature and history, and school training in them may be made as interesting as anything else in the curriculum. Upon such a foundation the University should surely be able to build a course devoted to literary, philosophical, historical, or philological learning even for the average student, provided that the University teacher undertakes the task of helping his pupils to learn for themselves, and to pursue their studies with a purpose, not merely as a preparation.

The spirit of inquiry which drives the literary student to find for himself the meaning of an author by study and by comparison of the views of others is really the same spirit of inquiry which drives the scientific student to interpret an experiment, or the mathematical student to solve a problem. Only by kindling the spirit of inquiry can teaching of a real University character be carried on. Give it what name you will, and exercise it in whatever manner you desire, there is no subject of study to which it cannot be applied, and there are no intelligent minds in which it cannot be excited.

The first question which a University teacher should ask himself is, 'Am I rousing a spirit of inquiry in my pupils?' And if this cannot be answered in the affirmative it is a confession that the University ideal is not being realised.

Some assert that this principle should also guide school education, and that it should be the first aim of the school teacher to stimulate the spirit of inquiry. My own view is that with young children this should be less necessary; they all possess it, and are by nature inquisitive. It should rather be the object of

the teacher not to spoil the spirit of inquiry by allowing it to run riot, nor to stifle it by making the work uninteresting; if the lesson interests them, their inquisitive minds will be quick enough to assimilate the teaching. We are, in fact, brought back to what I have already emphasised—that the real difference between the inquisitive mind of the child and the inquiring mind of the adult is that the former is yearning for information quite regardless of what it may lead to, whereas the latter must learn or investigate with an object if the interest is to be excited and maintained.

I have often thought it an interesting parallel that among original investigators and researchers there are two quite distinct types of mind, which have achieved equally valuable results. There is the researcher who pursues an investigation with a constant purpose and to whom the purpose is the inspiration. But there is also the investigator who has preserved his youthful enthusiasm for novelty and has in some respects the mind of a child; passionately inquisitive, he will always seek to do something new, and very often, like a child, he will tire of a line of research in which he has made a discovery, and take up with equal enthusiasm a totally different problem in the hope of achieving new conquests. I think that a man well known in Sheffield, the late Henry Clifton Sorby, must have been a man of this character. The latter is, perhaps, the most fertile type of original investigator, but it is not the type that produces the best teacher, except for very exceptional and original-minded students; and such teachers do not often found a school of learning and research endowed with much stability. For ordinary students the investigator who pursues his researches as far as possible to their conclusion is the safer guide.

It seems to me suggestive that there are to be found, even amongst the famous researchers, these two types of mind, that somewhat correspond to the mental attitude of the school pupil and the University student. It is as though these great men have preserved a juvenile spirit, some from the days of their childhood, others from early manhood.

It will now be clear that the principle which I am advocating is a very simple one, namely, that the business of direct mental training should be finished at school, and that at the University the trained mind should be given material upon which to do responsible work in the spirit of inquiry. Preparatory exercises belong to school life and should be abandoned at the University.

All this seems so obvious that it might appear to be hardly worth saying were it not that the methods which actually prevail are so far removed from this ideal.

When, for example, a boy who has not learnt Greek or chemistry at school comes to the University and proposes to take up one of these subjects he is generally put through a course of exercises which differ in no essential respect from those which are set before a boy of twelve. In other words, our University method for the trained mind does not really differ from our school method, which is supposed to be adapted to the mind in course of training. Again, boys who have been learning certain subjects for years at school, but are weak in them, have their education continued at the University in the same subjects by the same school methods until they can be brought up to the requirements of a first University examination, which in its character does not differ much from the examinations held at school. Where in this process is to be found the introduction of that spirit of inquiry and investigation which ought to characterise the University course?

It may be asked, In what manner is this change to be introduced, and how is it possible under present conditions, where so many students are all pursuing ordinary degree courses and have no time or opportunity for special work, to provide teachers who can educate them in this spirit, if it is also their duty to get pass students through their examinations? The answer, I think, is that in a University the professors and higher teachers should be, without exception, men who, whatever may be their teaching duties, are also actively engaged in investigation. Their assistants should be teachers who, even if the whole or part of their time is occupied in routine teaching, have yet had some experience in, and possess real sympathy with, modern advanced work under such professors. This is only to be secured by insisting that teachers in a University should all have had some experience of original work, and, just as one of the necessary qualifications

for an elementary teacher is some education in method, so a necessary qualification for a University teacher should be some education in research. Anyone desirous of qualifying for University teaching should be compelled to devote a certain portion of his student career to research, and the funds of a University cannot be better applied than to the retention of the better students at the University for the distinct purpose of enabling them to pursue investigation under the professor for a period of one year after they have completed their degree course, if they have not been able to do so during their undergraduate period. It is not, however, too much to hope that the majority of those who are endeavouring to qualify for the higher educational posts will be assisted to obtain this special experience during their degree course. Under the present system at most Universities, unless the student has been fortunate enough to come in contact with a teacher imbued with the spirit of research who is carrying on his own investigations, it rarely happens that he has the time or the means which would enable him to obtain any insight into the meaning of investigation before he leaves to take up teaching work. The need of post-graduate scholarships for this purpose is very widely felt, and is now frequently expressed. To insist upon such qualifications for all University students is, of course, under present conditions, impossible; but there should be no insuperable difficulty in insisting upon them for those who are to be allowed to enter a University as teachers.

Researchers are born, not made, and it is not by any means desirable that all University students should be cast adrift to make new researches and seek discoveries even under the direction of experienced teachers and investigators. This must depend to some extent upon the character of the pupil as well as of the teacher.

The mere publication of papers may mean nothing, and much that is dignified with the name of research is of no account. To turn a lad on to research, unless it be in the right spirit, may be only to set him a new exercise instead of an old one; to leave him to prosecute an investigation for himself may be to condemn him to disappointment and failure. On the other hand, to carry on any piece of work, whether it be new or old, in the zealous spirit of inquiry, with faith in a purpose, is to insure the intellectual interest of the student; and I cannot see why this spirit should not animate all University education, whether it be accompanied by original research or not. The essential condition is that the chief University teachers should themselves create an atmosphere of investigation.

So deep-seated is the belief that nothing must be undertaken without a preparatory course of training that even the best and most brilliant students are frequently discouraged from undertaking a new study until they have been subjected to the mental discipline of an elementary course in it.

I cannot refrain from quoting an example which came within my own experience, although I have already alluded to it in another address delivered last year.

When I was at Oxford a young Frenchman of exceptional ability, whose training had been almost exclusively literary and philosophical, and who was at the time engaged on a theological inquiry, expressed to me his regret that he had never learnt to understand by practical experience the meaning of scientific work. And when I assured him that nothing was easier than to acquire practical experience by taking up a piece of actual investigation under the direction of a scientific worker, he explained to me that when he had applied for admission to scientific laboratories he had been told that it was useless to do so until by preparatory courses he had acquired an adequate knowledge of mathematics, physics, and chemistry. I offered to make the trial with him, and began with a problem that happened to interest me and that required a new method of simple experimental research. I soon found that a well-trained mind, able to grasp the meaning of the problem and eager to investigate it, could begin without delay upon the experiments, and in the desire to interpret them could find a pleasure and a purpose in seeking the necessary chemical and physical knowledge; whereas to have begun by acquiring this in a preparatory course, with no definite object in view, would have been to set back a mature mind to school methods of training and very possibly to have stifled instead of kindling any real scientific interest.

This is, again, an illustration of my contention that the most special study, if

carried on in the true University spirit, is very far removed from ordinary specialisation, and involves very wide extension of interest and learning; whereas, if carried on in a preparatory spirit, it is necessarily limited.

In a very short time this student had published three original papers which seem to me of considerable importance, though perhaps on a somewhat obscure subject, and I see that they are now quoted as marking a substantial advance in knowledge.

Of course this is the exceptional case of the exceptionally able student; but I think it illustrates two things—firstly, the prevalence of the conventional attitude that preparation on school lines is necessary even for the post-graduate student; secondly, the fact that what is really necessary to the University student is the purpose, and that with this before his eyes he may safely be introduced to new fields of work.

One result of the conventional attitude is that those who have distinguished themselves at school in some subject are often assumed to have a special aptitude in it, and to be destined by Nature to pursue the same subject at the University, whereas their school success may only prove that they are abler than their fellows, and that this ability will show itself in whatever subject they may take up. Such students would sometimes on coming to the University be all the better for a complete change of subject, without which the continuance of the school studies too often means a perpetuation of the school methods.

Another result is that when teachers are always playing a somewhat mechanical part in a systematised course, receiving duly prepared pupils and preparing them again for the next stage, such an atmosphere of preparation is produced that many persons continue to spend the greater part of their lives in preparation without any reasonable prospect of performance.

I am well aware that, on the other hand, there always have been and are now many earnest and accomplished University teachers who are pursuing the methods that I advocate, whose teaching is always inspired with a purpose, whose pupils are stimulated to learn in the spirit of inquiry, and who consequently exercise a personal influence that is profound and enduring. I am deeply conscious how much I owe to some such teachers with whom I have studied and to others whom I have known. But still it does remain true that this is not yet the atmosphere of ordinary University education, that it does not yet invigorate the ordinary University student, and that to him the passage from school to the University does not necessarily mean a transition from mental discipline and preparation to mental activity and performance.

The distinction that I have in my mind between University and school teaching may be expressed in this way. At school no subject should be taught to a class as though it were intended to be their life work; to take an example, it too often happens at present, owing really to excessive zeal on the part of school teachers, that mathematics is taught as though each member of the class were destined to become a mathematician; consequently only the few scholars with a real aptitude for mathematics become interested, and the remainder are left behind. On the other hand, at the University each subject should be studied as though it really were the life work both of teacher and student. Thus, to take the same subject as an illustration, the mathematical student will attend the full courses of his professors and will follow them with the interest of a mathematician; whereas for the scientific student it will only be in those branches of mathematics which concern him that the interest of his special science will put him on terms of equality with the mathematical student. If I may choose an illustration which is familiar to myself, any student of mineralogy can easily be interested in and benefit by a course in spherical trigonometry, because it is one of the tools of his trade, but to send him to lectures on differential equations would be only to discourage him. On the other hand, the student of chemistry would rather be interested in the latter. To each of them certain branches of mathematics as taught by an ardent teacher afford a real intellectual training, but neither would gain much if compelled to follow a general University course of mathematics designed for mathematicians.

It will be observed that I have endeavoured to confine myself to the subject of University education and not to say much, except by way of contrast, concerning school teaching.

I must, however, return to it for a moment, if only to emphasise the danger of that specialisation, which, since it takes place at school and not at the University, is bound to be narrow, and which is often encouraged in pupils of special aptitude preparing for University scholarships.

That a boy or girl should for a year or even two years before leaving school be practically confined to one subject, and should before entering the University be examined in that alone, appears to me to be contrary to all the best traditions of school teaching, and to the often expressed desire of the Universities to insure a good general education in those whom they admit. There should, I think, be no scholarship examination which does not include several of the subjects of a normal school curriculum, however much additional weight may be given to any of them. Although it may be necessary that University entrance scholarships in one subject should be given either to encourage its study or to discover those who have a special aptitude, yet, so far as scholarships are intended to be rewards for intellectual pre-eminence, they should, I think, be directed to general capacity, and not be used as an encouragement to limited study. From what I have already said it will be clear that I do not attach much importance to special preparation at school for those who intend to proceed to the University. If a boy has a very special taste or aptitude, it should have abundant opportunity for displaying and exercising itself at the University, provided only that it has not been stifled, but has been given some encouragement in the school curriculum. I understand, for example, that those who teach such a subject as physiology at the University would prefer that their pupils should come to them from school with a general knowledge of chemistry and physics rather than that they should have received training in physiology. With the present modern differentiation into a classical and modern side, or their equivalents, the ordinary school subjects should be sufficient preparation for any University course if they are not mutually strangled in the pressure of an overcrowded curriculum.

To be fair, however, I must state another view. A very experienced college tutor who has had previous valuable experience as a master in a public school tells me that in his opinion the real problem of the public schools is the 'arrest of intellectual development that overtakes so many boys at about the age of sixteen.' 'There are few public schools,' he says, 'whose fifth forms are not full of boys of seventeen or eighteen, many of them perfectly orderly, well-mannered, and reasonable, in some sense the salt of the place, exercising great influence in the school and exercising it well, with a high standard of public spirit, kindly, and straight-living, in whom, nevertheless, it is difficult to recognise the bright, intelligent, if not very industrious, child of two or three years before.'

He thinks that there is a real danger of degeneration at this age, owing, for one thing, to the manner in which the boys are educated *en bloc*; up to a certain age boys can be herded together and taught on the same lines without great harm being done, but after a certain time differentiation begins to set in. The school curriculum, however, does not admit of being adjusted to suit the dawning interests of a couple of hundred boys; and he sees no cure for this difficulty except a considerable increase in the staff and a corresponding reduction in the size of the forms. But he thinks that much may be done by an alteration in the system of matriculation examination, which sets the standard at the public schools. He would make this consist of two parts: an examination coming at about the age of sixteen and well within the reach of a boy of ordinary intelligence and industry, and comprising the ordinary subjects of school curriculum at this age; he would then let the boy leave the subjects from which he is not likely to get much further profit and begin to specialise for the remaining two or three years, say, in two subjects, which would then be the material of the second examination. In this way they would make a wholly fresh start at a critical age, and he thinks that the bulk of the boys would probably find this a great advantage.

I quote this opinion because it shows that an experienced schoolmaster regards it as highly desirable that at a certain period in a schoolboy's career a real change should be made in his curriculum, and I have expressly stated that I find it difficult to express an opinion upon this particular educational period. What should be the exact nature of the teaching before and after the age of sixteen or seventeen for the mass of ordinary boys I would prefer to leave to the

decision of those who are best able to judge. I think it highly probable that there should be a considerable alteration of curriculum at the critical age. But, if a break and change of subject are required at this age, I believe that a yet more complete change is required at the later stage when the boy goes to the University, and that school methods should then be entirely replaced by University methods—not because there is then a natural change in the mental powers of the student, but because it is the obvious stage at which to make the change if we are to abandon preparatory training at all. Should it be proposed that the change ought to be made at sixteen, and that after that age something of the nature of University methods should be gradually introduced, my fear is that this would only lead to the perpetuation of school methods at the University.

An interesting question which deserves to be very seriously considered is the question, What sort of school education affords the best preparatory training for the University? I have often heard it asserted that, if a boy is capable of taking up at the University a course which is entirely different from his school course, he will generally be found to have come from the classical side and not from the modern side. An ordinary modern-side boy is rarely able to pursue profitably a literary career at the University, whereas it often happens that ordinary classical-side boys make excellent scientific students after they have left school. I am bound to say that this is, on the whole, my own experience. It suggests that a literary education at school is at present a better intellectual training for general University work than a scientific education. If this be so what is the reason?

There are no doubt many causes which may contribute. In some schools the brighter boys are still retained on the classical side while those who are more slow are left to find their way to other subjects; and some whose real tastes have been suppressed by the uniformity of the school curriculum turn with relief to new studies at the University and pursue them with zeal. But the facts do also, I think, point to some defect in the present teaching of school science whereby a certain narrowness and rigidity of mind are rendered possible. This may be partly due to the lack of human interest in the teaching of elementary science; the story of discovery has a personal side which is too much neglected, though it is more attractive to the beginner and might with advantage be used to give some insight into the working of the human mind and character. Moreover, it would form an introduction to the philosophy of science which is at present so strangely ignored by most teachers.

But another noteworthy defect is the absence of that mental exercise which is provided by the thoughtful use and analysis of language.

I believe that the practice of expressing thoughts in carefully chosen words, which forms so large a part of a good literary education, constitutes a mental training which can scarcely be surpassed, and it is unfortunately true that in the non-literary subjects too little attention is paid to this practice. In school work and examinations a pupil who appears to understand a problem is often allowed full credit, although his spoken or written answer may be far from clear. This is a great mistake. A statement which is not intelligibly expressed indicates some confusion of thought; and, if scientific teaching is to maintain its proper position as a mental training, far more attention must be paid to the cultivation of a lucid style in writing and speaking.

The various Universities seem fairly agreed upon the subjects which they regard as essential to an entrance examination—subjects which may be taken to imply the groundwork of a liberal education. Among these is English: and yet of all the subjects which children are taught at school there is none in which such poor results are achieved. It may be taught by earnest and zealous teachers; the examination papers are searching, and seem to require a considerable knowledge of English literature and considerable skill in the manipulation of the language, and yet the fact remains that the power of simple intelligible expression is not one that is possessed by the average schoolboy and schoolgirl. It is the most necessary part of what should be an adequate equipment for the affairs of life whether the pupil passes to the University or not, and yet it is on the whole that which is least acquired.

Although it is true that the intelligent reading and study of the great masters should assist in the acquisition of a good style, it is equally true that, if they

come to be regarded as a school task, they are not viewed with affection, especially in these days of crowded curricula, when there is little leisure for the enjoyment of a book that requires deliberate reading. If the modern strenuous curriculum of work and games has abolished the *loafer* it has also abolished leisure, and has therefore removed one of the opportunities that used to exist for the cultivation of literary and artistic tastes and pursuits by those to whom they are congenial. The art of expressing one's ideas in simple, straightforward language is to be acquired not so much by study as by practice. There is no essential reason why children should write worse than they speak; they do so because they have constant practice in the one and little practice in the other. Our grandparents felt less difficulty in expressing themselves clearly than we do ourselves: of this their letters are evidence. It may have been partly due to the fact that they had more time and encouragement for leisurely reading, though they had not so much to read; but I believe that the letters which they wrote as children were their real education in the art of writing English. Much would be gained if boys and girls were constantly required to express their own meaning in writing. The set essay and the *précis* play a useful part, but do not do all that is needed. Translation does not give quite the necessary exercise. What is required is constant, with certain periods of conscious, practice, and that is only to be obtained by making every piece of school work in which the English language is used an exercise in lucid expression. Very few paragraphs in anything written by the ordinary schoolboy—or, for the matter of that, by the ordinary educated Englishman—are wholly intelligible, and teachers cannot devote too much pains to criticising all written work from this point of view. If we first learnt by practice to express our meaning clearly we should be more likely to acquire the graces of an elegant style later. I must add that I believe the training in the manipulation of words would be improved if all children were required to practise the writing of English verse—not in efforts to write poetry, but narrative verse used to express simple ideas in plain language—and I believe that this would enable them the better to appreciate poetry, the love of which is possibly now to some extent stifled by the pedantic study of beautiful poems treated as school tasks.

In such a subject as English composition, in which reform is so badly needed, something, perhaps, would be gained by an entire break with existing traditions—a break of the sort which would be required if it became suddenly necessary to provide for an entirely new type of student.

Now, there is one new and interesting development in which, for the first time, an opportunity offers itself of dealing with a body of students who, although possessed of more than average intelligence and enthusiasm, have not received the conventional training which leads to a University course. The tutorial classes for working people which have now been undertaken by several Universities, and which already number about 1,200 students, are attended by persons carefully selected for the purpose and anxious to pursue a continuous course of study of an advanced standard. In these classes the Universities will be compelled to begin new subjects for students of matured minds who have not received the usual preparation, and will therefore necessarily deal with them in a new way. Here, if anywhere, the difference between school methods of teaching and University methods ought to be apparent; and I feel sure that, if University teachers attempt conventional methods with these students, they will be condemned to failure. It is certain that these classes will increase enormously and rapidly, and I have great hope that they will for this reason influence the methods of University teaching in a very healthy manner. In the tutorial classes the teachers will be confronted with the entirely new problem of students who have thought much, and of whom many are experienced speakers, well able to express their thoughts by the spoken word, but who, nevertheless, have received little training, and have had still less experience, in expressing their ideas in writing. Many of the students whom I have met have told me that this difficulty of writing is their real obstacle, and the matter in which they feel the want of experience most acutely. It will be a very valuable exercise for those who conduct these classes to instruct their students in the art of writing simple and intelligible English, and I hope that the necessity of giving this instruction will have a good effect upon the conventional methods of teaching English in schools as well as in Universities.

I am conscious that this address is lamentably incomplete in that it is concerned only with the manner of University teaching, and scarcely at all with its matter, and that, to carry any conviction, I should address myself to the task of working out in detail the suggestions that I have made. But this would lead me far beyond the limits of an address, and I am content to do little more than touch the fringe of the problem. Reduced to its simplest terms, this, like so many educational problems, involves an attempt to reconcile two more or less incompatible aims.

The acquisition of knowledge and the training of the mind are two inseparable aims of education, and yet it often appears difficult to provide adequately for the one without neglecting the other. If childhood is the time when systematic training is most desirable it is also the time when knowledge is most easily acquired; if early manhood is the time when special knowledge must be sought it is also the time when training for the special business of life is necessary. To withdraw from the child the opportunities of absorbing knowledge may be as harmful as it is unnatural; to turn a young man or young woman loose into a profession without proper preparation is cruel, and may be disastrous.

And so we get the battle of syllabus, time-table, scholarships, examinations, professional training, technical instruction, under all of which lies the disturbing distinction between training and knowledge.

But, if we inquire further into these matters, I think we shall find that the fundamental question is to a large extent one of responsibility. Left to himself, a boy or a man will acquire a knowledge of the things which interest him, even though they be only the arts of a pickpocket, and will obtain a training from experience such as no school or college can give. If education is to achieve the great purpose of interesting and instructing him while young in the right objects, and also of training him for the proper business of his life before it is too late, is it not mainly a question of deciding when and how far to take for him, or to leave to him, the responsibility of what he is to learn and how he is to learn it? If the teacher bears the responsibility during the period of school training, should not the student have a large share of responsibility in the quest of knowledge at the University?

Now, it is of the essence of responsibility that there should be something sudden and unexpected about it. If, before putting a young man into a position of trust, you lead him through a kindergarten preparation for it, in which he plays with the semblance before being admitted to the reality, if you teach him first all the rules and regulations which should prevent him from making a mistake, you will effectually smother his independence and stifle his initiative. But plunge him into a new experience and make him feel the responsibility of his position, and you will give him the impulse to learn his new duties and the opportunity to show his real powers. It is because I feel that this sudden entrance into an environment of new responsibility is so necessary that I would regard with suspicion any attempt to provide a gradual transition between school and University methods.

In matters of discipline and self-control it is possible and advisable to place responsibility upon school children; in intellectual matters it is not advisable, except for the few who are matured beyond their years. It is, therefore, all the more necessary that this should be done at the moment when they enter the University.

This should be the moment of which Emerson says: 'There is a time in every man's education when he arrives at the conviction that he must take himself for better or worse as his portion; that, though the wide universe is full of good, no kernel of nourishing corn can come to him but through his toil bestowed on that plot of ground which is given him to till. The power which resides in him is new in Nature, and none but he knows what that is which he can do, nor does he know until he has tried.'

The spirit of independent inquiry, which should dominate all University teaching and learning, is not to be measured, as I have already said, by the number of memoirs published, but it is to be tested by the extent to which University students are engaged upon work for which they feel a responsibility. Visit the Universities at the present moment, and, in spite of all the admirable investigation which is being carried on, you will find the majority of students

engaged in exercises in which they feel no responsibility whatever. In my opinion this indicates that for them the spirit of true University education has never been awakened. It is, after all, very largely a question of attitude of mind. Any subject of study, whether it be a scientific experiment or an historical event, or the significance of a text, is a matter of interpretation, and to approach it in the University spirit is to approach it with the question, 'Is this the right interpretation?' Upon that question can be hung a whole philosophy of the subject, and from it can proceed a whole series of investigations: it embodies the true spirit of research and it opens the door to true learning.

In discussing University education I have not, of course, forgotten that many persons have taught themselves up to a University standard entirely without the aid of professors; indeed, the University of London long ago provided an avenue to a University degree which has been successfully followed by many such persons with the best possible results. But I have endeavoured to remind you that at the University as at school for most students the personal influence of the teacher is the important thing; that at the University as at school success in teaching depends mainly on the extent to which the interest of the student is aroused; and that at the University this is only to be done by providing him with a purpose and a responsibility in his work in order that he may understand to what conclusions it is leading him. Until this is done we shall still have University students complaining that they do not see the object of what they are learning or understand what it all means. This complaint, which I have often heard from past and present students of different Universities, suggested to me that I should on the present occasion deal with this defect in our customary methods.

In the hope that the attention of University teachers may be turned more fully to this aspect of their work I have ventured to make it the subject of my address.

FRIDAY, SEPTEMBER 2.

Joint Discussion with Section H on Research in Education.

1. *Report on Mental and Physical Factors involved in Education.*
See Reports, p. 302.

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2. *A Research in the Teaching of Algebra.*
By Dr. T. P. Nunn.

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3. *Individual Variations of Memory.* *By* C. Spearman.

This paper dealt with the problem of the individual variations of memory. Lay, medical, and psychological views were cited. The present research, its experimental and statistical methods were described. As regards results the powers of memory for different kinds of material was always found to show some tendency to correspond, but in very varying degrees. The common view of psychologists that quick and retentive memories are wholly different powers was only partially corroborated and was traced to differences in the method employed for recall. Memory tests were found to correlate highly with teachers' estimates of 'general intelligence,' but the latter appeared to be based on obscure, variable, and not very reliable data.

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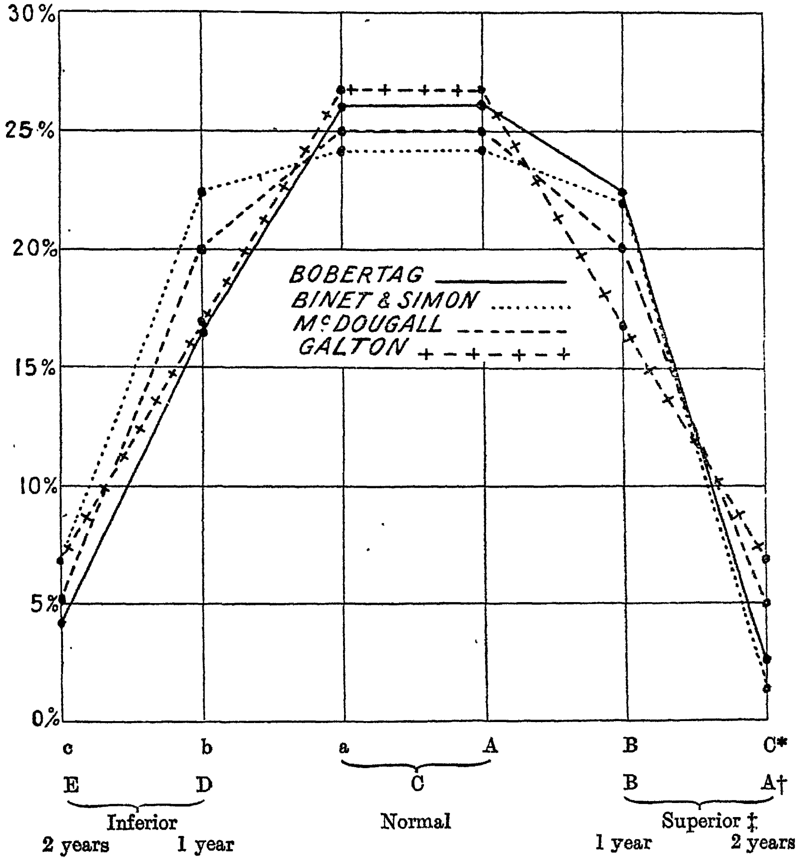
4. *On Testing Intelligence in Children.* *By* OTTO LIPMANN, *D.Phil.*

In dealing with the method, not the results, of investigations of intelligence in children reference was made principally to that followed by Binet and Simon[1] and by Bobertag in investigations, of which the results are not yet published. Starting with a definition of intelligence based on the concepts of 'leading idea' and of 'inhibition' it was shown that an intelligence test should be not merely a memory test. In employing intelligence tests certain limitations should be observed. Only children subject to like conditions should be compared, while



* Galton. † McDougall. ‡ Binet and Simon. Bobertag.

the chief result of the investigation will be to draw a boundary line between normal and sub-normal pathological cases.

Binet and Simon give a number of tests by which all the mental functions belonging to the intelligence may be investigated. They show for each age the tests which a 'normal' child might be expected to accomplish. The preliminary question, what percentage of the children of the same age are normal, is

[1] Binet and Simon, 'Le développement de l'intelligence chez les enfants,' *Année psychologique*, 14, pp. 1–94, 1908; Otto Lipmann, 'Die Entwickelung der Intelligenz,' *Zeitschrift für angewandte Psychologie*, 2, pp. 534–544, 1909; Otto Bobertag, 'Binets Arbeiten über die intellektuelle Entwickelung des Schulkindes,' *Zeitschrift für angewandte Psychologie*, 3, pp. 230–259, 1909.

answered by nearly the same number, whether the method of Galton, of McDougall (Mental Measurements Committee), or that followed in several other investigations is employed. This remarkable conformity is shown by the diagram.

If the supernormal individuals who accomplish the test are added the result is nearly always the same—a percentage of 77.

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5. *Experimental Tests of General Intelligence.* *By* Cyril Burt, *M.A.*

A series of experiments was carried out at Oxford two years ago, mainly upon thirty elementary school children, $12\frac{1}{2}$ to $13\frac{1}{2}$ years of age. The chief object was to determine the relative value, as tests of general intelligence, of a dozen brief tasks, involving mental processes at various levels, in various aspects, and of various degrees of complexity. By general intelligence was understood innate, unspecialised mental efficiency, as distinguished both from acquired knowledge, interests, and dexterities, and from specific endowment, aptitude, or talent. To form tests of general intelligence, the tasks were required, not necessarily to prove a means of measuring its amount in any individual child, but merely, with sample groups of children, readily and rapidly to yield results which should be reliable in themselves, and correspond to a constant and definite degree with the results of prolonged and careful observations of the teacher. The degree of correspondence was calculated by the method of correlation, and the coefficients obtained were taken as indicating the relative value of the tests.

Views attributing to sensory discrimination, whether general or specific, an intimate functional correspondence with general intelligence were not confirmed. Auditory and visual tests, indeed, showed positive, though not considerable, correlations with intelligence; but these seem rather to be referred to the dependence in the course of evolution of the progress of intelligence upon the perception of space and upon the perception of spoken words, and of these respectively upon delicacy of eye and ear. Tests of discrimination of touches and of weights showed approximately no correlations with intelligence. Simple motor tests, such as tapping and dealing, showed somewhat higher correlations than the sensory tests. But of the six simpler tests, sensory and motor, none gave correlations above 0·50.

The remaining six dealt either with processes of a higher mental level—such as memory, habituation, scope, and maintenance of attention—or with more complex mental processes, involving co-ordination of both sensory and motor activities, such as the 'alphabet' and 'dotting' tests devised by Mr. McDougall. Each of these six yielded correlations of over 0·50, the coefficients in the case of the last two being particularly high. An amalgamation of the results of the six gave correlations with intelligence of 0·85 to 0·91; and these figures are distinctly higher than those for the estimates of one teacher with another's, or with the results of examinations.

Further experiments have since been made in Liverpool at a mixed secondary school and at a secondary school for girls. The main object of these was to investigate three problems suggested by some of the limitations of the foregoing investigation—viz., how far such tests are affected by difference in sex, how far they can be undertaken with success by teachers untrained in a psychological laboratory, and how far they can be carried out as mass-experiments with numbers of children simultaneously instead of singly upon individuals. Tests have also been added to represent processes of the highest mental level—abstraction, judgment, inference, perception of relations—a level untouched by the previous research. The results indicate that, as compared with simple sensory or motor tests, tasks involving higher and more complex processes are vitiated to a far less extent by difference of sex in the subjects, absence of special training in the experimenter, and the peculiar conditions of experiments upon children in class. They also appear to possess the most intimate relations to intelligence. Tests, therefore, of this type seem the more practicable for educational investigations and sociological surveys upon a scale sufficiently extensive for statistical treatment of the results.

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6. *The Measurement of Intelligence in School Children.* *By* William Brown, *M.A.*

Although, from an abstract and formal point of view, it might be expected that a definition of intelligence should precede any investigation into the problem of its measurement, such an arrangement is only partially justifiable. Unless we are prepared to hypostatise intelligence as merely one of a number of 'faculties' displayed by the mind, we must face the problem of an all-inclusive survey of the mental ability of individuals; and if we possess the means of measuring the nature and degree of the interrelations existing between the various distinguishable factors of such mental ability, we *may* find ourselves justified in regarding the mind as some sort of *system* to which in its entirety, at least from one point of view, the name intelligence may best be applied. If such a result should emerge the problems of the measurement and the definition of intelligence would be solved simultaneously.

Since the mind, like the body, is *variable*, the method most applicable to the problem will be the statistical method of correlation. Taking a sufficient number of cases we may proceed to determine the magnitude of the tendency to concomitant variation displayed by the various subsidiary mental capacities distinguished by ordinary thought and measured by ordinary standards. To carry out this plan with any attempt at systematic completeness would involve the evaluation of the 'correlation ratio' (η) as well as the 'correlation coefficient' (r) for each pair of capacities under consideration, in order to determine the form as well as the degree of the correlation. A further indispensable part of the mathematical technique would be to apply the method of 'multiple correlation,' whereby, on a certain assumption (the assumption of linear regression) the magnitude of the tendency to concomitant variation possessed by any two of the capacities under consideration, *independently* of the tendencies of each to vary concomitantly with the other capacities, may be determined.

The author has applied this method to the investigation of the interrelations of part-capacities in elementary mathematical reasoning in eighty-three boys (already published[1]), and to that of the relations of elementary mental abilities to one another and to 'intelligence' as ordinarily measured, either by school marks or by 'general impressions,' and again by the specially devised *Combinatione-Methode* of Ebbinghaus, in the case of college students and elementary school children—about two hundred individuals in all, carefully segregated according to age, sex, and other 'irrelevant' conditions. The results show a certain general tendency to agreement among themselves, though indicating a much more complicated scheme of interrelation than that inferred—on somewhat inadequate data—by the champions of a 'central factor.' The correlations are also '*low.*'

Much of the correlation hitherto appealed to as evidence of the existence of one single central factor 'is undoubtedly spurious' in nature, *i.e.*, arising from irrelevant factors, such as the influence of strange apparatus on the children, personality suggestion, differences in degree of discipline to which the various members of the groups examined had been accustomed, &c. The mathematical formulæ, again, which have been employed to demonstrate this central factor from the crude correlation results are much too abstract, involve too many improbable presuppositions to be of any practical applicability. The method of 'multiple correlation' is the only sound and rational one for the investigation of the law of relation of the various correlation coefficients to one another, but it has never been employed in this connection by the investigators referred to.

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7. *Perseveration as a Test of the Quality of Intelligence, and Apparatus for its Measurement.* *By* John Gray, *B.Sc.*

Perseveration depends on an elemental property of the brain which determines the persistence of mental impressions or the rapidity with which one impression can follow another. It may be measured in various ways, one of the best being by Wiersma's colour disc. On this disc are two colours which can be seen

[1] *Biometrika*, vol. vii., No. 3, April 1910.

separately when the disc is rotating slowly, but as the speed of the disc is gradually increased a point is reached when the two colours fuse into one uniform tint. This critical speed is a measure of the perseveration of the subject being tested.

Gross has shown theoretically how the mental character of the subject may be deduced from his or her perseveration, and the experiments made by Wiersma and others agree very closely with Gross's theoretical deductions. Perseveration indicates the quality of the intelligence rather than its amount; persons with high perseveration may be described as slow-intelligent, and those with low perseveration as quick-intelligent. There is a considerable range of perseveration among normal persons, but when it passes above or below certain limits it is usually associated with insanity of different kinds. Acute maniacs have abnormally low and melancholics abnormally high perseveration. A description was given of an improvement on Wiersma's disc devised by the author, in which illuminated coloured glasses are reflected into the eye of the subject by a revolving mirror. This enables the luminosity of the colours to be regulated. Results of tests made by the author on visitors to the exhibitions at the White City were given, and an interesting hypothesis on the connection between perseveration and colour blindness.

8. *Experimental Work on Intelligence.* *By* H. S. LAWSON.

Experiments have been performed on groups of boys between the ages of nine and sixteen. These groups are as follows:—

(*a*) Elementary-school boys who were within two months of nine years on January 1, 1909. (I.)

(*b*) Elementary-school boys who presented themselves for a scholarship examination at a Midland grammar school. Age limit, thirteen years. (II.)

(*c*) Students in the same grammar school. (III.)

I. These boys have been submitted to twelve tests of intelligence, each of which has been given for a period of from three to twenty days. In every case the functioning of the higher mental levels is involved. The correlations between the various methods of diagnosing intelligence have been arranged in the form of a hierarchy, wherein that test which has been proved objectively to be most intellective in nature takes first place.

II. These candidates were submitted to simple tests of intelligence at the close of the official scholarship examination. The coefficient of correlation between official and unofficial (the present writer's) order of merit was, in 1909, 0·217, and, in 1910, 0·485. The similarity of position was most marked in the upper strata. The coefficient for the '1910' examination was higher than that which obtained between any two individual orders of merit in the official examination. In the latter, examination papers were set in arithmetic, history, geography, grammar, composition, and dictation.

III. Several classes in the grammar school have from time to time been given exercises to perform, in which processes of reasoning are involved. An amalgamated order of merit for the several forms has been produced. The coefficient of correlation between these respectively and the term's order for the various classes engaged has been calculated. In every instance a high number has been obtained.

The career of the scholarship students is being watched. Public examinations are a useful criterion whereby to gauge the relative merits of the two methods of 'spotting ability' outlined in this abstract.

9. *M. Binet's Method for the Measurement of Intelligence.* *By* Miss KATHARINE L. JOHNSTON.

With M. Binet's help given at the Laboratory, Rue Grange aux Belles, Paris, I have applied his tests for estimating the level of intelligence to 200 school girls of Sheffield.

The tests are part of a more extensive examination which has as its object

the complete understanding of a child who comes before us, and if they are what their authors hope them to be, they will assist teachers who desire to determine the reasons for the lack of progress of pupils, or to gain knowledge of the intellectual calibre of a new pupil. As an example of their nature I give those employed for children of nine.

They are asked (i) to give the exact date of the day, (ii) to enumerate the days of the week, (iii) to define fork, table, chair, horse, mother (the definitions given are to be superior to 'use' definitions), (iv) to read the following: 'Burton-on-Trent, 6 January. Last night a great fire at Burton-on-Trent destroyed three houses situated in the centre of the town. Seventeen families are homeless. The losses exceed 150,000*l*. While saving a child in its cradle a barber's assistant was seriously burned on the hands'—and after a brief interval to recall at least six facts. (v) Having before them a heap of money containing 1*l*., 10*s*., 5*s*., 2*s*., 1*s*., 6*d*., 3*d*., 1*d*., ½*d*., and in addition three pence and seven half-pence, to enact the part of a shopkeeper, selling a small article for four half-pence. The purchaser tenders 1*s*. in payment, and change is demanded. Various solutions are possible, the best being the sixpence, the threepenny bit, and one penny. (vi) Being given five boxes of identical shape and appearance, but 3, 6, 9, 12, 15 grammes respectively in weight, to arrange them in order of weight; three attempts are allowed, two of which must be correct.

The investigator on this method deals with the individual, and a little preliminary talk is necessary to insure confidence. The child's age is then ascertained, and the tests for that age given; should he accomplish all or all but one he is adjudged at the level of that age, and is then subjected to *all* the tests of the succeeding ages. If he accomplishes five of these a year is added to his level; if ten, two years. But, if the child fail in two or more of the tests appropriate to his own age he is put through the tests of each preceding year in turn until that year is found in which he can accomplish *all* the tests or all but one.

My experience is that one of the greater hindrances to exactitude lies in the investigator; it is impossible to be certain that one has preserved identical tones of voice and expression of face throughout the sittings, and with a subject so susceptible to suggestion as a child the doubt will creep in that the result has thus been vitiated. Then there is the difficulty of estimating the results. Thus one of the tests requires the children to make a sentence containing the words London, River, Fortune. If I allow the construction 'London river' M—— C—— (twelve years) is at the twelve level; if I do not allow it she is only at the level of ten years, and since she cannot do five tests superior to that level she must be adjudged backward.

I have found that it is the exception rather than the rule for a child to be able to satisfy the tests for her own age, *e.g.*:—

Of	4	children of	6 years	.. ..	2 have to go back.
,,	41	,, ,,	7 ,,	.. ..	26 ,, ,, ,, ,, 9 can do the tests for 8
,,	22	,, ,,	8 ,,	.. ..	15 have to go back. 1 can do the tests for 9.
,,	25	,, ,,	9 ,,	.. ..	20 have to go back. 5 can do the tests for 10.
,,	37	,, ,,	10 ,,	.. ..	23 have to go back. 2 can do the tests for 12.
,,	23	,, ,,	11 ,,	.. ..	20 do the tests for 10. 3 can do the tests for 12.
,,	22	,, ,,	12 ,,	.. ..	16 have to go back. 1 can do the tests for 15.
,,	20	,, ,,	13 ,,	.. ..	16 have to go back. 4 can do the tests for 15.
,,	3	,, ,,	14 ,,	.. ..	2 have to go back. 1 does the tests for 15.
,,	3	,, ,,	15 ,,	and over ..	2 have to go back. 1 does the tests for 15.

The provision for adding one year for five tests superior to the level reached, or two years for ten, mitigates the severity of this judgment. Thus, of the

fifteen children eight years old who had to go back, excluding one in whose case the tests were not completed, only three in the final reckoning are to be adjudged backward.

I have found cases in which girls could satisfy the tests of a superior level, but were unable to satisfy the tests of their own age or of the age immediately preceding it. M. Binet was prepared for such cases, and the child who presents this characteristic is estimated as of the intellectual level of the year, at which she fulfils the required number of tests.

10. *On Testing Intelligence in Children.* *By* Professor Dr. Ernst Meumann.

The outcome of the author's reflections can be shortly expressed in the following sentences :—

(1) The test methods cannot be dispensed with because of their great practical value.

(2) To be excluded are all tests of acquired knowledge, especially the examination of school knowledge and use of school work, because some of them may be lacking in any normal child. Because of this it becomes impossible to determine the normal standard of intelligence which would be of general validity for each life year and for all children from any Milieu. *But this is the principal demand for a general comparing research into the normal child and its development.*

(3) Therefore the tests have to be reduced to merely functional examinations.

(4) It is impossible to measure the general intelligence with one or a few psycho-analytical tests and very difficult and uncertain with one or only a few practical tests. It is therefore better to give up the thought of being able to determine the general intelligence by tests methods; instead of these we seek to examine the higher intelligence, which apart from the testing of a few elementary functions, principally sensibility and sensibility of difference for some senses, is to be considered as the working-up of impressions or representations by synthetical and combinatory thinking.

(5) This is best obtained by all the methods which examine the working with abstract elements, the working with leading representations, the working with the solution of combinations which are accustomed, easy and rich in content, and the combining of them with combinations of new representations and the connection of these to the leading representations.

11. *The Pitfalls of 'Mental Tests.'* *By* Charles S. Myers, *M.A.*, *M.D.*

A protest was entered against the collection of vast quantities of psychological data, especially by an army of untrained observers. Nothing can be more dangerous than the supposition that the consequent errors cancel one another 'in the long run.'

In physical anthropometry, despite the standardisation of measurements, considerable differences occur when practised observers measure the same individual. What must be the degree of divergence when *mental* characters are measured by untrained observers, who not only improperly use and read their 'instrument,' but affect in different ways the attitude of their subjects towards the test!

Within any given community the individual variations in physical, and no doubt also in mental, characters are so wide that the average of any measurement must differ very widely from the average of that measurement in another community, for the difference between the averages to be with certainty significant. Indeed, it must be large enough to be apparent to the unprejudiced eye. Thus the statistical treatment of racial mental characters does not *discover*, so much as *measure*, racial differences. Accuracy is therefore essential.

The statistician who aims at collecting pyschological data in large numbers is apt to neglect the various influences which, in different degrees, affect different subjects in the tests, and to pour all data from whatever source into the statistical

mill, which, in consequence, expresses a psychologically meaningless result. This is especially apt to occur in the case of correlations, in the calculation of which different observers so frequently disagree.

A subsidiary cause of this discrepancy is due doubtless to racial differences in correlation. The racial differences which undoubtedly exist in the correlations of physical measurements almost certainly have their counterpart in respect of mental measurements. So the correlation in a heterogeneous people may in one sample of it be high, in another be low or reversed; in one sample the probable error may be great, in another small, according to accidental differences in racial diversity.

But the main cause lies in the neglect of the introspective element. The only way to ascertain *what* is being tested by psychological experiment is to have recourse to the subject's experience. Owing to neglect of this a test of mental fatigue may not involve mental fatigue at all; it may in different subjects involve the play of complicating factors (automatism, boredom, duty, ambition) in different degrees. So, too, a positive correlation between general intelligence and sensory discrimination may be due to the fact that the very nature of the test has compelled the subject to use his intelligence while carrying out sensory discrimination. To avoid spurious measurements and correlations of this kind, too much care cannot be taken to find out exactly what factors the experiment involves; and this can only be done by individual introspection, which is impossible in the blind wholesale collection of data by untrained observers.

We are prone to hope that statistics will yield results out of all proportion to the value of the material put into them. Only collect enough data and a valuable conclusion will emerge! Nothing can be farther from the truth, especially in regard to 'mental tests.' The treatment of such data *en masse* is apt to give a mere blur, which hides mental processes actually existent and claims to reveal others that have no existence.

Mass-experiments, however, have their use. In everyday life we do not care *how* an individual works, *how* he knows; we want to know *how much* he can work, *how much* he knows. For this purpose we require standards of productiveness, standards of knowledge, which will differentiate, for example, the feeble from the normal and will mark the progress of the former. But let us clearly recognise that these are not psychological tests. Let us not spoil two good things by pretending that tests of production are a measure of definite mental processes, for from the psychological aspect the results are a mere blur.

MONDAY, SEPTEMBER 5.

The following Papers were read :—

1. *The Teaching of Handicraft and Elementary Science in Elementary Schools as a Preparation for Technical Training. By* J. G. LEGGE.

The elementary school's right aim—a general education to form the basis of specialisation later. So, too, with the secondary school, though there now recognised that there is no one type of general education, and consequently both at home and abroad various types, each with a particular colour or bias, are being developed. Why not similar variety of types in the case of elementary schools?

The particular variety under discussion to-day—a practical curriculum for boys in a town school, leading naturally on to technical education. Part played by British Association, notably in Reports of 1906 and 1908, in establishing claim for introduction of handicraft and experimental science into the curriculum. Impetus towards this given by Board of Education's recent Memorandum on Manual Instruction in Elementary Schools.

The scientific basis for the practice of manipulative work—development of brain centres presiding over co-ordinated movements of all kinds. Variety of purposes in view when principle thus established is advocated, and consequent variety of means for applying it. No one single purpose in view, and therefore no one single method of applying principle possible.

Freedom to head-teachers to frame curriculum, but a useful, and at same time scientific, division of school above infant stage into juniors, children rising to the age of twelve, and seniors, children of and over twelve. Simple forms of handicraft and courses of object-lessons suitable for the junior stage. The schemes of all classes to be carefully co-ordinated by the head-teacher.

In the senior stage the curriculum to be arranged in two divisions or on two sides, which may be termed the literary and the constructive. Half the school accommodation for seniors to take the form of classroom, half the form of workshop. Boys to work in two shifts, morning and afternoon, alternating between classroom and workshop. Division of subjects of curriculum between the two sides. The literary side to lay stress on independent study on the 'note-taking' basis, mathematics to be common to the two sides; and the handicraft, while admitting of a measure of absolutely free work, to be closely co-ordinated with a scheme of practical physics, in which mechanics will hold a prominent place, practically all apparatus and rough working models being made by the scholars.

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2. *Educational Handwork: an Experiment in the Training of Teachers.* *By* JAMES TIPPING.

The Educational Handwork Association has during the last eight years conducted a most interesting experiment in the training of teachers in educational handwork.

This vacational course has met annually during the month of August in the Municipal Secondary School, Scarborough, and has attracted an increasing number of teachers from every part of the British Isles, and not a few from the Continent, the Colonies, and America.

The aim of the promoters has been to make handwork better understood, and, indeed, to demonstrate its value and necessity in an ideal scheme of general education.

The need for mind-training through muscular activities has been urged by educationists of all times, but administrators of education have not so readily appreciated the psychological aspect of the problem, and consequently have made the mistake of developing the work for its economic value rather than for any truly educative ends it might serve.

The purely utilitarian aspect of the various forms of manual activity has been the means of leading them away from the true intention of the work with the usual result that the 'means' have been mistaken for the 'ends,' the 'avenues' to knowledge have been mistaken for the 'goal.'

Manual training as an industrial training has no place in the ordinary school curriculum, but as a factor in mind development its presence is essential.

Probably the term 'manual training' too readily suggests industrial activity, and to this extent it is somewhat of a misnomer; hence the reason why this Association favours the title Educational Handwork, because it more readily expresses the essential difference between industrial activity and muscular activity, which leads to brain training.

The predominating feature of handwork is the use of a variety of tools and materials and the adapting of them to given ends. The more materials used the better, for each has its characteristic requirement in the way of handling and moulding into due form.

In the development of schemes the central ideal has been to give due consideration to the two points of view—namely, the technical and psychological. So far as children are concerned, the latter is essentially of primary importance, whilst technic as such takes only a secondary place; but from the point of view of the teachers' needs both are requisite.

Reference to the schemes of work on exhibition emphasised the fact that whilst the technical courses provide for the development of the teachers' executive powers, every opportunity has been taken of developing suggestive ideas for the application of such knowledge to the children's needs. Power to initiate such schemes as will apply to the varying capacities of the children is what is aimed at, rather than the following of set schemes worked in the training

school and slavishly adhered to by the teachers when they go back to their own schools.

In the kindergarten, of all places in the school, psychology plays an important part, and in the summer school this is kept constantly in mind. A daily lecture is given, after which the various forms of manual expression, such as brush-drawing, claywork, raffia, paper cutting, folding, and mounting, are discussed from the standpoint of child psychology.

In clay-modelling the objects which are of interest to children and the methods they would adopt in the making of such at different ages are taken into consideration in working out the course. The psychology of touch is appealed to in discussing the methods of handling the material.

In working out a brushwork course the statistics with regard to children's ability to discriminate colours are appealed to; samples of children's own spontaneous work are examined, and the students are trained to analyse them, estimate their worth, and take hints for future guidance from them. Similarly in drawing and paper-cutting the problem of the perception of distance and of the third dimension in objects is worked out, and the children's powers in these directions at kindergarten age discussed; the value and limitations of the different forms of colour and form are worked out and criticised from that basis. In sewing and weaving the mechanism of visual adjustments is reviewed and made the basis for criticism of the use of such material as are utilised in mat-plaiting and calico for sewing for young children, so that the students are given definite reasons why sewing should be on coarse materials and with coarse thread, and why wool and raffia are superior as weaving materials to mat-plaiting.

The teachers are shown that the school occupations may easily be made extensions of the child's natural and instructive home occupations; he loves to build thread beads, make marks with chalk or pencil, to splash about with colours, and in these directions his play may readily be developed and enriched by the proper use of such in school.

The first essential in the kindergarten work is to get rid of the idea of courses in different materials, the aim being rather to give the child ample opportunity to use a variety of materials in the expression of central-group experiences.

The first principle in dealing with kindergarten teachers is to train them to develop in the child the power of self-expression, and next to familiarise them with a variety of materials, so that they can constantly appeal to his powers of expression in these materials, and so strengthen his powers of selection and adjustment.

In the various schemes of work on exhibition it will be noted that the fundamental principles governing kindergarten methods are arranged and elaborated to suit the more mature development of the children as they pass through the different stages of school life. As the child grows physically and mentally the mode of approach varies somewhat, and the development of mind through the activities becomes an ever-increasing and more highly complex problem, but through the medium of clay, card, wood, and metal there is afforded an infinite variety of experiences that can be utilised to harmoniously develop the child both physically and mentally.

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3. *Handwork in relation to Science Teaching: the Manipulative Skill of the Teacher.* By G. H. Woollatt, *Ph.D., F.I.C.*

Science teaching in most schools is now dominated by the research idea, and it is therefore an essential that the lessons given and the experiments performed shall follow lines determined by the students themselves rather than a course definitely set out in a given syllabus beforehand.

One of the chief difficulties of a teacher in this respect is that of procuring suitable apparatus. Usually he is bound to apparatus which is catalogued by the various apparatus dealers, and his course of lessons is to some extent hung upon the pegs of purchasable apparatus units, instead of the apparatus being made to fit the experiments. In elementary schools this is even more the case than in secondary and technical schools, for the allowance for science apparatus is smaller, and the stock of it therefore still more limited. To stock a quantity of apparatus

on the principle of a possible use being found for it is sheer extravagance, and as much apparatus deteriorates in value upon keeping it is not a defensible policy. Yet, as already stated, one can scarcely tell for more than a week ahead what may be required.

A teacher of science in any school must possess the skill which will enable him to assemble standard units of apparatus in such a way as to make it possible to conduct almost any experiment, and the principle of supplying such standard units has been in vogue since science teaching began; yet a glance around schools will usually show many quite elementary and more or less clumsy attempts at the setting up of simple apparatus. In other words, the science teacher rarely has found time to acquire the skill necessary to enable him to deal efficiently and neatly with the many and various materials that come under his notice. When he is able to command the services of an expert laboratory attendant his work is easier, but even then his possible experiments are bounded by the skill of his attendant and the apparatus shops. His work is thus frequently confined within limits which are unnecessarily and uneducationally small.

The remedy is to make all science teachers and all laboratory and lecture attendants pass through a course of instruction in the use of simple tools such as could be supplied to any laboratory, and in the various methods usually adopted in the manipulation of different materials used in the construction of apparatus. It is necessary also for a science teacher to know the properties of the various materials he uses and the limits to which he may strain and torture them; also his own capabilities in the direction of manipulation.

This remedy has been applied more or less during the past fifteen or twenty years in certain colleges, but in some cases the object has been defeated by supplying all the materials cut to size, so that only the erection of the apparatus to be constructed fell to the teacher-student. During the past five years, however, the Department of Agriculture and Technical Instruction in Ireland (which controls the science teaching in that country) has made it possible for their teachers to attend a systematic course of training such as that outlined above, and to attain, in the space of a few weeks, a training in the use of tools and materials sufficient to enable them to deal with most of the ordinary work which falls to the lot of the science teacher.

The course followed is roughly one of a hundred hours, of which less than twenty hours are spent in the lecture-room, the work in the lecture-room being mainly concerned with the reasons for the shapes of tools, the theory of their action, the manner of keeping them in working condition; the properties of materials and the reasons for the use of various materials for specific purposes. The Department also includes in its lecture course instruction upon the construction and use of the projection-lantern, upon apparatus and diagram design, the care of tools, apparatus, benches, bottles, and other laboratory appliances, and similar subjects.

The practical work consists of four main divisions—work in wood, metal, and glass accounting for the first three, and a general section following, in which many of the ordinary processes of a physical laboratory are undertaken—processes which all teachers ought to be able to demonstrate, but which unfortunately are only possible with definiteness and certainty to few. This section includes such work as the copying in plaster or in copper of some small objects, the grinding and drilling of glass, the silvering of glass, cementing of various similar or dissimilar materials together, the cleaning of mercury, the preparation of microscope-slides, lantern-slides, the making of scales upon glass, &c.

It is not the object of the course to turn out makers of apparatus, and for many purposes it is not necessary that the work done should have any high finish; it is mainly desired to impart the skill in the handling of materials such as will enable and encourage a teacher to set up his own apparatus in his own way for an experiment, and, further, to enable him to set out a correct specification for any instrument he requires and which may be beyond his power to construct, for it is always made clear to students that much of the apparatus available for scientific work would not pay a teacher for the making; his time is more usefully employed in other directions.

Teachers in Ireland no longer are the only ones to enjoy the privilege of attending such a course, as during the past three years a similar one, of three

weeks' duration, has been held in August at the Municipal Schools, Scarborough. under the auspices of the Educational Handwork Association, and any teacher in Great Britain now has the opportunity of becoming a skilled manipulator of apparatus and of material. It is encouraging to be able to report an annually increasing number of students in this subject.

A teacher who has been through such a course as this is no longer restricted in his apparatus. He is able to design or devise a new method of showing old facts: he is able to make a piece of apparatus simply and easily for the demonstration of any point requiring special attention, and he is able to overcome many of the greatest difficulties that beset a teacher of science—those of replacing small portions of broken apparatus, of readjusting faulty instruments, and of increasing the general efficiency and reliability of the apparatus under his care.

In these circumstances the work of such a teacher becomes a more personal exposition than could otherwise be the case. The very kind of experiments performed and the type of apparatus chosen and used become an indication of the line of the teacher's thought. Each school laboratory will gradually acquire a tone from the influence of the man in charge, and so to some extent reproduce the results of the old days, when our great teachers—Black, Cavendish, Bunsen, and others—taught with home-made apparatus, much of which certainly indicated the personality of the maker. It was suggested that such a state of things is much more desirable than the present one of hundreds of laboratories containing the same units of apparatus, all used in the same way, with almost the same words in the explanations given.

Furthermore, the capability of making small apparatus and appliances encourages a teacher in the use of the projecting-lantern for delicate experiments—an immense educational advantage—and keeps him constantly on the look-out for new and pretty (therefore attractive and easily remembered) ways of performing his demonstrations.

Specimens of students' work, illustrating the course followed in these training classes, were exhibited. The specimens were all made by students in the Laboratory Arts Course, August 1910, Scarborough Summer School Educational Handwork Association.

Joint Discussion with Section B on the Neglect of Science by Industry and Commerce.[1] *Opened by* R. BLAIR, *M.A.*

TUESDAY, SEPTEMBER 6.

The following Papers were read:—

1. *Outdoor Work for Schools of Normal Type. By* J. EATON FEASEY.

Anxiety with respect to the physique of school children has led to the multiplication of open-air recovery schools. The value of these schools from the hygienic standpoint is beyond question, and their work on the educational side is not unsatisfactory. A danger arises, however, of outdoor educational work being mentally associated with, and practically restricted to, the physically defective. Against this it is urged that an immediate and large increase in the amount of school-work in the open air would not only benefit children and teachers physically, but is on educational grounds very desirable for all classes in schools of every type.

At present teachers are largely slaves of the schoolroom and the desk. Outdoor work is restricted to drill and gardening, with, in some few schools, an occasional walk or excursion. Things which cannot be done at a desk in a room are looked upon with suspicion as not being the real work of a school. Yet all are aware of the serious harm done to growing children by desks necessarily unsuitable, and of the impossibility of providing well-ventilated rooms and sufficient floor-space. In many districts school accommodation is deficient in nearly all hygienic

[1] See *The School World*, October 1910.

requisites, and aggravates the harmful influences present in many cottage homes. But the advantages of open-air work are not mainly hygienic, but educational. It is impossible in the classroom to use as we ought the child's natural love of movement and his instinctive restlessness. Outside this characteristic natural activity may be used and the evils of wrong desk-posture and vitiated atmosphere avoided.

There are difficulties of organisation connected with school journeys and objections to technical instruction in horticulture as a school subject. Whether these are or are not overcome, there is a large amount of work which can and ought to be done outside. The adoption of the asphalted playground has increased facilities in this direction, whilst the provision of school gardens would enormously widen the possibilities of work in the open air in immediate proximity to the school.

There is much work of high educational value which can only be done outside. There are educational methods which can be adopted in the playground and not in the classroom. There is abundance of work which can be more efficiently done in the open air.

Photographs were shown of classes engaged in such work. Children were shown during lessons in arithmetic, mensuration, and geometry on the playground floor, and it was noticed that the larger available space makes co-operative work possible to the class. This form of work was recently urged upon rural teachers by the President of the Board of Education.

Other illustrations showed children taking first lessons in heat and light. Such teaching surely should always be taken outside, the sun being employed rather than a lamp. The biological importance of light and heat can be shown by continued observation and experiment with living, growing things in the garden. Other illustrations showed the practicability on the school premises of outdoor lessons on direction, the sundial, shadows, seasons, &c.

But it is with work included under the term 'nature study' that the adoption of outdoor methods is most urgent. It is surely wrong to confine children within doors to discuss snow, rain, wind, dew, sunshine, and plant life. 'Blackboard Nature study' is surely an absurdity.

There is a crying need for the multiplication of school gardens, not for technical instruction in horticulture, but for the conduct of real Nature Study. The garden should not merely provide the material for, but should be the scene of the lessons. Illustrations of classes doing such work were shown. Much of this work cannot be done on an excursion. In the garden scholars may carry on prolonged investigations—*e.g.*, into rate of growth. The Nature instinct born in a child can be satisfied and developed instead of being obliterated by work in school with a dried or torn-up specimen. The garden offers unlimited scope for teaching the child through his own observation and inference.

Comenius in the seventeenth century urged that every school should have its garden and use it in this way. England is exceedingly backward in this respect as compared with some other countries.

It is not impossible to meet the difficulty of providing gardens for schools in the congested parts of cities. Plots of ground might be laid out in the suburbs and classes conveyed to these garden schools for a half-day each week for outdoor work of various kinds. No plans should be passed for new suburban or rural schools unless a garden is provided, and H.M. Inspectors could do much by urging the importance of making playgrounds and gardens the scene of lessons.

The physical and educational value of such work is perhaps exceeded by its æsthetic and moral advantages.

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2. *The School Journey: its Practice and Educational Value.*
By G. G. Lewis.

Actual objects are better teaching tools than the most vivid description, better even than pictures, lantern slides, or models. Big things like trees, hills and rivers, castles and cathedrals, cannot be brought into the class-room, and smaller objects are best studied in their own natural environment. Hence the need for school journeys. Four kinds of school journey are attempted at Kentish Town Road School.

1. *The Open-air Lesson.*—Each class spends one half-day on Hampstead

Heath (one mile away). The time-table shows drawing, geography, drill, Nature study. If wet these subjects are taken at school; if fine, drawing is combined with geography or Nature study the whole afternoon. Typical work includes tree study; scenery study—hills, rivers, valleys, rocks, &c.; map reading and making, contours; plant œcology; pond life; clouds, snow, and atmospheric effects; 'colonisation' and 'seeking hidden treasure.'

2. *Saturday Rambles*—*e.g.*, to Epping Forest for toadstools; Richmond Park for pond life; Charlton Quarry for rocks and fossils.

3. *Long-distance Excursions.*—A week's visit to some distant centre—*e.g.*, Chepstow, Abergavenny, Shanklin, the Cotswolds, Folkestone (with day trip to Boulogne). The cost, from 18s. to 21s. per head, is borne chiefly by the parents. Forty to fifty boys, aged from seven to fourteen, are taken. They have always been taken in the Easter holiday, as all teachers are anxious to be with their boys. In London the journeys may be done in school time. The Children's Country Holiday Fund will send children to cottages for a fortnight, the L.C.C. providing teachers. The ideal party would consist of three teachers, an organiser, treasurer, and house-master, with thirty or forty boys. It is well to prepare a guide-book containing maps, historical notes, &c., for each boy. It is cruelty to insist on copious notes or descriptions on an excursion when the boys are out journeying every day. Rough sketches with the briefest notes should suffice.

4. *The Open-Air School* in Epping Forest.—The whole of the top class (thirty-five boys) spent four days at a 'Retreat' in Epping Forest in July with their masters at a cost of 6*s*. per head. School lessons were followed in the forest according to the time-table in the mornings, a journey being taken in the afternoon.

'*Our Aims*' (from the Guide-Book).

1. To bring teachers and scholars into closer touch with one another.
2. To foster habits of good fellowship, self-reliance, and unselfishness.
3. To investigate the causes which produce scenery.
4. To secure rock, plant, and animal specimens unobtainable near London.
5. To extend our knowledge of mankind past and present.
6. To gain health and vigour from a week in the open air.
7. To learn how to spend a holiday intelligently and happily.

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3. *School Gardening.* *By* ALEXANDER SUTHERLAND.

Many claims are made for gardening as a means for interesting and educating children. The claims are that gardening has important intellectual, social, moral, industrial, and æsthetic values. If so, it is the duty of everyone to help in bringing about a larger use of the subject.

About 30¼ square yards, or 60 feet by 27 feet, with central path of 4 feet, was found by the writer to be a suitable area for two boys, one above 12 and the other under. When girls are at sewing, the boys go to gardening. The advantages noted are: (1) It vivifies school work, stimulating all branches of study; (2) It gives the subject of Nature study a definite foundation, suggesting problems through which children may be trained to 'do something in order to find out something'; (3) It teaches respect for labour, showing the importance of the work of producing vegetables, and of the skill desirable for this fundamental human employment; (4) It brings the interests of the home and school more into sympathy; (5) It tends to correct modern pleasure-seeking tendencies, developing interests that furnish means of wholesome pleasures within ourselves; (6) It expands the mind by the opportunities it gives for observation of various plants of different kinds; (7) It brings the school into sympathetic association with our most important industry—agriculture—and gives a simple, recreative manual training in handling a spade and other garden tools; (8) It awakens interests and desires that help in the formation of good habits, and healthy, profitable employment in spare time; (9) It enhances the usefulness of the citizens by the training towards special interests that he may follow up after school days are over, and help in producing plants—living things of beauty and wonder.

Conducting School Gardening.—There must be co-operation between pupils and teachers. The practical operations of preparing and cultivating the soil, planting the seed, &c., devolve on the scholars. Scope for the directive, stimulative, educative influence of the teacher find a field here for securing skill and interest.

Observations on the first appearance of seed leaves, buds, where the buds grow, and how they open, visits of bees and other insects, where nectar is stored, colours of flowers, what parts of them fall off and what parts remain, weed studies, names and families of garden weeds, bulb culture, planting of bulbs for spring bloom, planting in pots for indoor winter blooming, setting out tulip bed in school grounds—all full of interest, full of instruction, in which help given and help got will ever be a pleasant and profitable experience to all concerned.

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4. *A Training College under Canvas.*[1] *By* Professor MARK R. WRIGHT.

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5. *The Agency of Notations in the Development of the Brain.* *By* Miss A. D. BUTCHER.

In this paper the following matters were referred to: The retention of the present relations between the spoken and the written expression of sense; the restoration of those relations which have been obscured by the vicissitudes attending the development of the human race; the opinion of Victor Egger; language in its origin has nothing to do with sound—it is a state 'un mode de moi-même'; English ideography; sign, sound, and sense in the same symbol; man a *silent* reading animal; description of orthoëpic notation; the digraph character of English print; international ideographs; printing reform before spelling reform; the proportionate value of phonetic elements; the anomaly of a fifteenth-century print in the twentieth century; the economy of nervous force in teacher and pupil; orthotype in the kindergarten; the importance of printing reform from a commercial point of view; English the Esperanto of the future.

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6. *On some Effects of the Extension of the Elementary School System on the English Character.* *By* S. F. WILSON.

This paper dealt with the following subjects: Prevailing dissatisfaction with the results of general and compulsory education in England; elementary education in England one of the most difficult problems ever raised in any country; the relation of natural education to school education: brief history of the latter during the last eighty years; natural inequality of children insufficiently recognised; limits of teaching by verbal concepts; importance of psychological atavism; effects of the scientific interpretation of Nature on elementary teaching; the effects of the elementary school on political and social controversy and reform; the present deadlock in legislation regulating the status of the elementary school; the necessity of improved ideals and methods in the elementary school.

Joint Discussion with Section I on Speech.

(i) *The Evolution of Speech and Speech Centres.* *By* Dr. ALBERT A. GRAY.

Speech develops as a result of hearing, hence it is not surprising that the centre in the brain for the understanding of speech is in close proximity to that for the sense of hearing, and, indeed, may for some purposes be considered as part of that centre. The centre for the understanding of speech, however, is limited to the left side, while that for hearing is found on both sides of the brain. The centre for hearing is termed the audito-sensory centre, and that for the

[1] Published in *The School World*, October, 1910.

understanding of speech is termed the audito-psychic. Hence when these centres are destroyed on both sides the individual becomes quite deaf and does not understand speech. If the centres be destroyed on the left side only he hears what is spoken because the right audito-sensory centre is still intact, but he does not understand what is said because the audito-psychic centre is present on the left side only and is destroyed. If the hearing centre on the right side only is destroyed the individual can still hear and understand speech.

The centre for the production of speech is found on the left side of the brain in the third frontal convolution and adjacent regions. Since this centre is only concerned in the production of speech it follows that when it is destroyed the individual can still hear and understand what is said to him, but he cannot frame words and sentences to express himself in speech.

Mechanism of the voice : The voice is produced by the vibrations of the vocal cords, and, for the most part, the various tones depend upon the portions of the cords which vibrate and the degree of tension in these portions. The changes in the extent and tension of the vibrating portions of the vocal cords are determined by muscular action, which in its turn is governed by the centres in the brain described previously. The voice is resonated in the cavities of the mouth, pharynx, and nose; hence by altering the size and shape of these cavities by means of movements of the tongue, palate, &c., the quality of the tones produced in the larynx can be affected at will.

(ii) *The Essentials of Voice Production. By* Professor WESLEY MILLS.

At the present time it is vital for those who teach especially to agree on some principles. Only principles, and not 'methods,' except those based on a few fundamentals, are possible. It is better to abandon the term 'method' if applied to anyone's systematic teaching. It is more important to emphasise what is common in the teaching and practice of speaking and singing than the differences. Other things being equal, the more of a singer the speaker is the greater his success. For the singer, training in speaking should for a time precede training in singing or be carried on with it.

The double purpose of speaking and singing.

The justification of the appeal to science.

The object of cultivating vocal technique or voice production.

Its psychic and somatic factors.

Adjustment or co-ordination of the psychic and somatic and of the various parts of the vocal mechanism is the key to explanations and to practical success.

The vocal mechanism consists of three main parts. In using these the subject employs neuro-muscular mechanisms controlled by psychic factors. The psychic must precede the somatic. At first results are largely voluntary; later reflex and sub-conscious. In all muscular movements, those concerned with voice production included, sensations are of vital importance. In phonation the chief sense is hearing, but others, usually associated with muscular movements, are also essential. Without these 'voice-placement' is impossible.

The essentials of a good tone.

Breathing in relation to voice production. The practice of the old Italian vocal teachers is not inconsistent with the latest investigation on breathing. The 'attack'; the resonance chambers; parts to be used and parts that may interfere with a good result.

Good voice production does not necessarily constitute good art, but is essential to it.

The term 'accent' as now often used is unsatisfactory.

The value or quality of vowel sounds should be settled by an international commission of experts. The same applies to a few consonants, especially 'r.'

EVENING DISCOURSES.

FRIDAY, SEPTEMBER 2

Types of Animal Movement.
By Professor WILLIAM STIRLING, *M.D., D.Sc., LL.D.*

The discoveries of great men nvr leav us—thy are immortal, they contain those immutable truths which survive the shock of empires, outlive the struggles of rival creeds, and witness the decay of successive religions.' These are the words of the historian of civilisation, and to them may be added those of Mr. Roosevelt in his Romanes Lecture at Oxford : 'In the world of intellect, doubtless the most marked features in the history of the past century have been the extraordinary advances in scientific knowledge and investigation.' We must all admit that modern progress in certain directions is largely due to inventions and discoveries the 'offspring of the scientific mind.'

It seems all the more remarkable, therefore, when we find Von Uexküll in his wonderfully suggestive book, 'Umwelt und Innenwelt der Thiere,' asking the question, 'What is a scientific truth?' He himself gives his reply, 'An error of to-day.' This reply reminds one of other questioners after truth, and also of the remark of Napoleon. 'What is history,' said he, 'but a fable agreed upon?' There is food for reflection in these replies, both for the man of science and the historian. I shall try to show you what science has achieved in the investigation of animal movements, and in doing so I must refer briefly to the historical aspect of the question, for it is just two years more than three centuries since the founder of the study of animal movements was born in the fortress of Castel Nuovo at Naples.

Linnæus, in his oft-quoted maxim, 'Stones grow,' 'plants grow and live,' 'animals grow, live, and feel,' seems to have omitted the most characteristic feature of living animals, for undoubtedly amongst all manifestations of life the features which are most striking, most characteristic, most interesting, and to us most intelligible are of a mechanical order, as represented by movements of various kinds, whether movements of one organ on another or movements of the animals themselves—on land, in water, or through air—the three great Highways of Nature.

Movement, though not a characteristic of animals alone, is in them so marked as practically to become a distinctive feature. Their immense power of generating mechanical motion enables them to perform those actions which constitute their visible lives. The subject presents an endless field of inquiry to the anatomist, to the physiologist, to the artist, and not least to the pathologist.

Nothing is more remarkable in Nature than the variety and, on occasion, the apparent simplicity of the mechanisms for the production of movements both in animals and plants. 'Every chemical substance, every plant, every animal in its growth teaches us the unit of cause, the variety of appearance.' As Emerson expresses it, 'Nature is an endless combination and repetition of a very few laws. She hums the old well-known air with innumerable variations.' Perhaps nowhere is this more evident than in the sphere of movement.

The motor organs themselves have been far more carefully studied than the movements they produce, but there are not wanting signs that the impulse given to morphological studies by the doctrine of adaptation under natural selection has begun to affect the study of purely physiological problems, in proportion as it becomes daily more evident how infinitely fertile are the movements of organisms as a field for the study of adapted reactions.

The wonderful harmony existing between the form and functions of a muscle, the marvellous co-operation of groups of muscles to produce specific movements, are revealed everywhere in animals as well as in the human frame itself. The co-ordination takes place in the higher animals in the central nervous system, a system characterised by autonomy as well as centralisation, a system so complex that a few years ago its main highways could only be guessed at, but which now, thanks to the labours of experimental physiologists, pathologists, and histologists are as well known as the great high-roads that intersect the country itself, and they are maintained in a far more workable condition than obtains even in the best roads. We also know the side-paths from these main nerve tracks, and, thanks to the genius and researches of Sherrington, we have reached a measure of finality, for have we not in reflex actions a 'final common path' towards which converge a multiplicity of private yet ever open and serviceable paths with a free right of way? Orderly 'behaviour' characterises the outward visible movements of animals, as well as the sequence of events in the internal, invisible motor organs on which the continuance of life itself depends. As the movements of animals are intimately related to their habits and modes of life, this opens up another aspect of the question.

Animal movements may be classified according to the media on or in which the animal moves. In terrestrial progression the ground is a more or less fixed or rigid point of support or fulcrum. The action of the moving limb tends to repel the fulcrum in one direction, and the body itself in the opposite direction. The more solid and resistant the ground, the greater will be the amount of energy available to propel the body forward. The energy, however, is generated by the animal itself. Everyone knows how little progress he makes on a shifting, feebly resisting surface such as sand. In aquatic progression, as in the swimming movements of a fish, the fulcrum is the water, which is freely mobile and easily displaced, so that much of the energy is dissipated in moving the water itself. The specific gravity of a fish is approximately that of the water itself. Some animals are moved by the expulsion of water from the body—in the jelly-fish the bell contracts and forcibly expels water, while the cuttle-fish expels the water in its mantle through its funnel. The animals are propelled in an opposite direction. The lowest microscopic water-dwellers move by indefinite limited contractions and expansions of the protoplasm, of which their microscopic bodies are made up. Others are propelled by the rhythmical vibrations of cilia on their surface or by the undulations of a membrane.

As air is eight hundred times lighter than water, aerial motion presents the most interesting of all problems. It has been solved by insects and birds alike, and both of these flying motors are heavier than air. The air fulcrum is far more mobile than the aquatic or terrestrial support, yet in spite of this the greatest velocities are obtained in aerial progression.

If we adopt a more popular classification, depending on the number of legs possessed by animals, we have bipeds, quadrupeds, centipedes, and even millipedes. In these hundred-footed creatures the marvellous co-relation of their segmental limbs excites our wonder, while the exact analysis of the sequence of movement almost baffles our methods of study. Some of you know the disturbances of motor acts that are produced in human beings when a person is mentally excited, or on occasion when he may be the object of scrutiny by an onlooker.

Borelli. De Motu Animalium.

In the seventeenth century there began that glorious period of scientific endeavour and achievement, the period of Harvey, Galileo, Torricelli, Malpighi, Redi, and Stensen, the period when new methods were applied to the study of physics with such brilliant results. In a humble convent cell in the monastery of San Pantaleone in Rome, on the last day of the year 1678, and as the New Year was coming in, there died the founder of the Study of Animal Movement, Giovanni Alfonso Borelli. He was born in Naples in 1608, the son of a Spanish soldier, and a Neapolitan mother, whose name was Borelli. His name stands in the forefront as a great pioneer and founder of the study of animal movement. After being educated in Rome he became professor of mathematics in Messina about 1640, and in 1656 he was called by Ferdinand Duke of Tuscany to Pisa, where he

had as a friend and pupil Marcellus Malpighi, and where he taught publicly his doctrines and the results of his investigations, and also wrote a large part of his great work *De Motu Animalium*. Twelve years later he returned to Messina, which he left as an exile in 1674, and went to Rome, where he lived for a time under the patronage of that remarkable woman, Queen Christina of Sweden. The decennium passed in Pisa was the most brilliant period of his scientific life. Here he had as pupils Marcellus Malpighi, who dedicated to him his famous treatise *De Pulmonibus*; and also Lorenzo Bellini, whose name still survives in the tubules of the kidney. Borelli was one of the founders of the famous Accademia del Cimento. His home in Pisa was at once a 'domo,' and also perhaps the first physical and biological laboratory in Europe. Here also was taught 'Anatomia in domo Borelli' by Claudius Anterius. The Grand Duke of Tuscany himself saw that he was supplied with the necessary animals for his experiments. The problems of animal motion presented a field for the application of the new methods of physical research which had been established by the labours of Galileo and his fellow-workers. The investigations of movements as manifested by animals and man was a large part, but not the only part, of his life-work. His researches were published in his epoch-making book *De Motu Animalium*, the first volume in 1680—two years after his death—and the second in 1681.

Borelli applied to living beings the laws of mechanics, and he reduced to its simplest form the theory of animal locomotion. He recognised that these movements 'are due to mechanical causes, instruments, and reasons.' Mathematician, geometrician, astronomer, and physicist, and the first physiologist of his time, Borelli combined in his life-work the happy marriage of geometry with physiology. Just as Harvey's work recorded in 'il libello d' oro' was the compliment to the anatomical period of the sixteenth century and the labours of Vesalius, so Borelli's monumental work continued that of Harvey, and co-ordinated and brought into relation other functions of the body. Over twenty years of his life were spent in Messina, and when he quitted Sicily he found refuge in Rome. Robbed by his servant of practically all his belongings, old, infirm, and poor, he found in the last years of his life a peaceful resting-place amongst the Fathers in the Collegio di San Pantaleone dei Padri delle Scuole Pie, and it was these Padri who found the money and published his monumental work of 900 quarto pages, illustrated by nineteen magnificent plates crowded with artistic and vigorous delineations.

The comparison of animals with machines is both legitimate and suggestive, and, indeed, it is a very fertile, if trite, idea, and the justice of the comparison becomes far more apparent now than in the days when Borelli unravelled living mechanisms as a problem in animal mechanics. At the end of the seventeenth century the chemical aspect of the question was just dawning. A rational chemistry was springing out of the work and dreams of the alchemists. The time had not arrived for the consideration of living organisms as 'chemical machines,' consisting essentially of colloid materials, which possess the peculiarities of automatically developing, preserving, and reproducing themselves, to use the words of Jacques Loeb in his most suggestive lectures on 'The Dynamics of Living Matter.' There were, however, prophets in the land, and not the least interesting of these is Dr. Samuel Johnson himself, who appears in a new *rôle* as the prophet of man's conquest of the air. In 'Rasselas' he makes his hero say: 'I have long been of opinion that, instead of the tardy conveyance of ships and chariots, man might use the swifter migration of wings, that the fields of air are open to knowledge, and that only ignorance and idleness need crawl upon the ground.' We also find Victor Hugo among the prophets. In 1864, writing on the subject of aerial navigation, the poet expresses the opinion that the flying machine of the future will be the 'hélicoptère,' that it will be 'heavier than the air.' It was to be the bird flying where it listeth, while the balloon he compared to the clouds, wafted, driven, and tossed by the winds at their will. Looking at a balloon in the air one day, he said to Arago: 'See the egg soars. The bird has yet to come. But the bird is within, and it will be hatched.' To-day the prophecy has been fulfilled.

Borelli took all animal movements for his province, and dealt both with external visible movements and movements of internal organs with voluntary and involuntary movements. The various types of terrestrial locomotion he not unsuccessfully compared to the methods by which a boatman directs a boat. He studied the stability and displacement of a fish, and illustrates by an original

figure the principle of a diving-bell or submarine-boat. Marey points out that Borelli gave the first correct explanation of the flight of a bird. The wings act on the air, as he said, like a wedge—after the manner of an inclined plane—in order to produce a reaction against the resistance of the air whereby the body of the bird is driven forward. Marey himself admits the correctness of Borelli's theory, while modestly only claiming for himself the subordinate merit of having furnished the demonstration of a truth already suspected.

The Graphic and Photographic Methods.

The introduction of exact physical and chemical methods completely revolutionised the subject of physiology, especially from the period of Johannes Müller onwards. On the physical side no method contributed more to this advance than the 'Graphic Method.' It is a very remarkable fact that though man for centuries—indeed, for thousands of years before the Israelites crossed the Red Sea, about 1500 B.C.—had been writing or recording his thoughts in various graphic characters, by the skilled movements of his own right hand, on *stationary* surfaces, it was only about six decades ago that the movements of other parts of his mechanism were recorded on a *moving* surface driven by clockwork. A more exact analysis and interpretation of animal movements was not possible until the graphic method had been applied to the study of movements which are either too rapid or of too short duration to be followed by the unaided eye. About 1800 Thomas Young recorded time by means of a vibrating metallic rod on the surface of a cylinder. James Watt inscribed the movements of the indicator of his steam-engine on a cylinder, moved by the engine itself. In physiology the impulse towards the application of the graphic method came through Carl Ludwig in 1847, when he invented an instrument which he called a 'Kymographion,' or Wave-writer. Thus for the first time was recorded the beat of the heart as expressed in the variations of pressure within the arteries. I shall show you to-night a lantern-slide copied from the original tracing taken by Ludwig on December 12, 1846. I owe this to my friend Professor A. Mosso, of Turin, to whom Ludwig presented a portion of the original tracing.

The graphic method was rapidly extended to the study of all kinds of physiological and other phenomena. New apparatus in the form of 'myographs' and other recording instruments were invented. Time was accurately recorded by vibrating tuning-forks and by chronographs. Problems deemed insoluble a few years before, thanks to the labours and investigations of Helmholtz, du Bois Reymond, and above all to Professor Marey, of Paris, were brought within the range of the experimental method. More, however, was still required. Photography soon lent its aid, and to-night I shall show some remarkable results of the application of cinematography to the study of physiological movements as exhibited by the microscopic forms of life so numerous in water, as well as the movements of parasites that live in the blood, and are the cause of some of the most fatal diseases to which man and animals alike are subject. This I am able to do through the kindness of Messrs. Pathé Frères and Dr. Comandon. My best thanks also are due to the Gaumont Co., Ltd., for recording for me a special series of films expressly taken to illustrate this lecture, but which, I hope, may prove useful to other physiologists. I believe there is a great future for the application of the cinematograph to physiological problems, both as a means of investigation and in teaching.

Notes on the Illustrations.

The first type of animal movement selected was that of Amœba; lantern slides were shown to indicate its changes of form, mode of feeding, movements and reactions to stimuli such as have been described by Jennings. Many attempts have been made to explain Amœboid movements by artificial imitations of protoplasmic activities. The imitations are based on the assumption that these phenomena in Amœba and other protoplasmic masses are due to local changes of surface tension in a fluid mass—a view associated with the names of Quincke, Bütschli, Rhumbler, and others. Gad, in 1878, placed a drop of rancid oil on a dilute solution of carbonate of soda. The fatty acid acts on the oil, a soap is formed; this lowers the surface tension at various points of the drop of oil, and as a result the drop changes its form and sends out projections having an external

resemblance to the pseudopodia of Amœba. In order to illustrate these artificial imitations a cinematograph film was projected of Gad's experiment. In order to make the oil visible on the clear fluid carmine was rubbed up with the oil. The feeding movements of Amœba were also shown. Among the most interesting of these is the experiment of Rhumbler, in which a drop of chloroform in water takes in and rolls up within itself a very fine thread of shellac. A similar process occurs in Amœba Verrucosa when it comes in contact with a green filament of an Alga, as is described and figured by Leidy. Copies of the original figures of Leidy and Rhumbler were projected on the screen.

The ciliated group of Protozoa were then considered, special attention being given to Paramœcium—a small, unsymmetrical cigar-shaped animal, just visible to the naked eye, and covered with over 3,500 cilia arranged in oblique rows, the cilia forming about $\frac{1}{200}$th part of the entire weight of the animal. The cilia propel the animal in the water in which it lives, and as they move backwards with five times the energy they vibrate forward the animal is propelled forward, always, however, in a spiral course having a straight axis, a device which is marvellously effective, and is used by many aquatic animals. As the animal moves forward the cilia around the mouth cause a backward current of water, carrying food to the animal. Thus as it speeds along it can sample the water, take in its food, and do what the best submarines cannot do. It takes in its fuel, water and oxygen, *en route*, as it navigates the abysses of its pool. On meeting any obstacle in its path it has a wonderfully effective mechanism for avoiding these obstacles, the so-called 'avoiding reaction,' so graphically described by Jennings. It reverses its engines—its cilia—automatically swims backwards, turns to one side, and swims forward in a new direction. This backing-out process may be regarded as a negative reaction. It also shows marked positive reactions collecting in certain areas or in water containing dilute acids, an example of what it called 'Chemotaxis.' By means of films specially prepared by Dr. Comandon the movements of Paramœcium were demonstrated, the film giving a vivid representation of the wonderful life in the water peopled by Paramœcium and other organisms. Such a result is obtainable by photographing objects on a dark ground, the ultra-microscope being employed. Some other films by Dr. Comandon were shown to illustrate the microscopic flora and fauna of the intestine of a white mouse. A film of a Spirillum which moves by means of flagella was also shown.

The work done by cilia was demonstrated by means of a film specially prepared for the lecture by Messrs. Gaumont. The lower jaw was removed from the brainless head of a dead frog. On the front part of the palate was placed a large piece of the animal's liver, and on this a flag. The liver and flag were rapidly carried backward right into the gullet. The effect of heat in quickening the motion was demonstrated in the same way. The experiment illustrates what the combined action of thousands on thousands of cilia can do, as well as the importance of their action in removing secretions or other particles from the tubes or channels which they line. If their action is impaired—and it is wholly uninfluenced by the nervous system—or if the cells bearing them are shed, as in bronchitis, then the secretions accumulate in the tubes and block them. By means of a stroboscope an analysis of ciliary motion was projected on the screen to show the movements of the individual cilia and the combined action of the whole. By using a mechanical slide of another type the progressive and rolling movements of Volvox were also projected.

Passing to fixed ciliated protozoons such as Stentor and Vorticella, their characteristic ciliary movements were shown by means of slides, while a film was used to show the movements of Vorticella and the contractions of its stalk into a spiral by means of the myoids, or primitive contractile filaments that extend from its bell into its stalk.

Movements of animals by means of undulating membranes were next considered, and those of Trypanosomes were taken as the type. Trypanosomes occur abnormally in the blood of many different animals, from fish to man. A particular form in man's blood and in his cerebro-spinal fluid is the cause of the fatal malady 'sleeping sickness.' Their movements in the blood of a rat were demonstrated by means of a film specially prepared by Dr. Comandon, in which these animals, propelled onwards by their flagellum and undulating membrane, could be seen forcing their way among the blood-corpuscles.

Passing next to the movements of sea-anemones, coloured slides were exhibited to show their general configuration, and in many their exquisite beauty of coloration. The reflex actions, spontaneity, and co-ordination of movements shown by these animals is by some attributed to the presence of a nervous system; others, such as Loeb, regard their movements and responses to stimulation as due to the general characteristics common to all protoplasm. Loeb's experiments of feeding a sea-anemone with a wad of paper dipped in crab juice, and another wad moistened with sea water, were described, and also his experiments on the beautiful Cerianthus. First the remarkable 'righting' movements of a Cerianthus placed head downwards in a glass tube, and then similar movements, the animal righting itself when laid on a perforated zinc plate or wide-meshed wire gauze—an example of what is called Geotropism.

The remarkable observations of Bohn on Atlantic Actinia that live between high and low water mark were referred to. The animals, when removed to an aquarium where they are constantly and completely under water, expand their tentacles at high water and close them at low water. This rhythm is retained for several days. Parker's observations on Metridium were mentioned, as well as those of Gamble and Keeble on Convoluta.

The fascinating problems suggested by the rhythmically pulsating bells of the Medusæ or jelly-fish, so carefully investigated by Romanes, were next introduced. Their forms and beauty were shown by coloured slides reproduced from the works of Allman and Haeckel. The animal is propelled by the expulsion of water by the contraction of its bell, so that the animal itself is propelled in the opposite direction—a method adopted by some other aquatic animals. The contractions or beats are as orderly as the beats of the human heart itself, and at once suggest a comparison with cardiac rhythm. In the naked-eye Medusa (Sarsia), which was shown, Romanes found that complete removal of the extreme margin of the bell caused immediate total and permanent paralysis of the entire organ, while the separated portion continues its contractions; if a small piece of the margin is left attached to the bell the umbrella still contracts. Romanes inferred that in the naked-eye Medusæ there are centres of spontaneity for the origination of impulses to which the contractions of the swimming-bell are exclusively due. The quiescent marginless Sarsia, if stimulated mechanically, respond with a single beat, just as does the ventricle of a frog's heart brought to a standstill by the application of the first ligature of Stannius. The impulse to movement and co-ordination are due, according to Romanes, to the presence of the nervous system, *i.e.* are neurogenic, while Loeb from his experiments on Gonionemus—an American form—ascribes the beat to ions which serve to bring about the labile equilibrium of the colloid condition of the protoplasm. The locomotion of this simple animal is due to the contraction and relaxation of one thin sheet of muscular fibres which bring about co-ordination. During the contraction phase the bell does not respond to stimulation; it is inexcitable or refractory—a stage called the 'refractory phase.' It is this which prevents disharmony when multiple stimuli are applied during the contractile phase. A refractory phase was first noticed in the heart by Kronecker and Stirling many years ago. Marey studied it carefully and gave it its present name.

The Echinoderms represented by sea-urchins and starfish were next considered. The observations of Romanes and Preyer were illustrated by means of slides. The movements of the tube feet were shown by the cinematograph; then followed a film to show their 'righting' movements, and another to show Astropecten burying itself in the sand by means of its tube feet. The researches of Von Uexküll on these animals and on the brittle stars were next referred to and similarly illustrated. Von Uexküll regards the sea-urchin as a 'republic of reflexes.' The movements of a slug have to suffice for the Mollusca. The shadow of a living slug was projected on a screen, and the retraction of its horns demonstrated on the animal itself and the mechanism by which it is brought about by means of a model.

The subject of flight was dealt with very shortly, the observations of Da Vinci, Pettigrew, Marey, Lendenfeld, and others being referred to, including the recent researches of Mons. L. Bull carried out at the Marey Institut at Paris. By an ingenious apparatus, a dragon-fly—Agrion—was cinematographed, and through the kindness of M. Bull the original film was projected. The animal makes about

thirty-five beats of the wings—it has two pairs—per second. The electric spark was used, and by this means an enormous number of exposures per second can be obtained. The wings make a figure of 8 movement from behind forward, while in birds the figure of 8 described by Pettigrew is from above downwards.

The following table from Marey shows the number of vibrations per second made by the wings of certain insects :—

Name.	Per Second.
Common Fly	330
Drone Fly	240
Bee	190
Wasp	110
Humming-bird Moth	72
Dragon-fly	28
Butterfly, White	9

The work of Borelli on the flight of birds was illustrated by a copy of Borelli's original figure. The splendid work of Marey by the graphic and photographic methods was referred to. There is one striking fact about the flight of birds—viz., that the pectoral muscles which move the wings are equal to one-sixth of the total weight of the animal. The following table from Marey shows the number of vibrations per second :—

Name.	Per Second.
Sparrow	13
Wild Duck	9
Pigeon	8
Moor Buzzard	6
Screech Owl	5
Buzzard	3

The last part of the lecture dealt with reflex action as the physiological unit in the operations of the nervous system, the subject being represented by the reflex movements of a pithed brainless frog, and by the protective reflexes of such animals as crabs, lizards, &c., which, as shown by Fredericq, amputate a limb or the tail when limb or tail is violently seized. That animals can still execute well co-ordinated movements after certain injuries to the nervous system was illustrated by showing a film of a frog climbing an inclined plane and maintaining its equilibrium after removal of its cerebrum. The stepping movements of a dog, in which Professor Sherrington had completely divided the spinal cord, were also shown. As to the movements of internal organs, some films were projected to show the heart beating after removal from the body of the frog, tortoise, and rabbit. The last films showed the excised heart of a rabbit, prepared by Dr. Locke and perfused with his fluid, beating and recording its beats on a moving blackened cylinder, the effects of chloroform on its beats, stopping them, and the recovery of the beat after washing out the chloroform; and to give an example of a rhythmical beat due to alterations of surface tension, the rhythmical beats of a globule of mercury, known as 'Ostwald's physical heart,' were projected.

MONDAY, SEPTEMBER 5.

Recent Hittite Discovery. *By* D. G. Hogarth, M.A.

The object of the lecture was to show in outline how the memory of the Hittites as an imperial people has been recovered and what their place in world-history was. This recovery dates from the finding in 1834-35 of two prehistoric cities at Boghaz Keui and Uynk in North-Western Cappadocia. Their sculptures and inscriptions were ultimately recognised by Sayce as belonging to the same family as certain inscriptions and sculptures which had been found at Hamath and elsewhere in Syria after 1870, and also some other monuments observed in

Asia Minor, at Ibriz and near Smyrna. These Syrian monuments had been already ascribed to a people which, under the name of *Kheta* or *Khati*, played a large part in the Syrian relations of Pharaohs of the XVIIIth to the XXth Dynasties, and in those of the Assyrian kings; and this people, it was generally agreed, was identical with the 'children of Heth' or Hittites of the Old Testament. If the latter were responsible for the monuments in question in Syria, then, too, they were responsible, in some sense, for the monuments in Asia Minor; and, in any case, it was clear that a very peculiar and important civilisation, covering a large area of the Nearer East in the second millennium B.C. and the early part of the first, had been forgotten by history.

Scholars and explorers made continual efforts during the next quarter of a century to elucidate this civilisation, and succeeded so far as to place its origin in Asia Minor, and to fill up, more or less, by the discovery of many new monuments the geographical gaps dividing those first observed. They found that these monuments lay, roughly, along lines of communication leading from North-Western Cappadocia to the south and west, and they established in fact that not only Northern Syria but West Central Asia Minor showed such monuments in almost every part. But fundamental questions—who were the authors of this civilisation? where precisely was its chief focus? and who shared its development?—had still to be left open; and it was not till Boghaz Keui came to be excavated by Winckler and his companions in 1906-07 that they could be answered.

At the last-named site, known for some years to produce cuneiform tablets partly in Babylonian, partly in an unknown tongue, the excavators explored a large megalithic group of ruins in the lower city and fortifications, and certain other structures in the upper, besides clearing and re-examining the long-known religious rock-reliefs of Iasily Kaya. Besides several mural sculptures, of which the most interesting shows an armed Amazon, the explorers came on a number of cuneiform tablets, chiefly in the ruins of the earlier portion of the lower megalithic building, which was evidently a palace. These tablets proved to be in the main Foreign Office archives of six generations of kings, who ruled over the Hatti of Boghaz Keui in the fourteenth and thirteenth centuries B.C. They conclusively prove that the Hatti of Cappadocia were the *Khati* who fought with Egypt at Kadesh, and made the famous treaty with Rameses the Great. The first important reign was that of Subbiluliuma, contemporary of Amenhotep IV.; the last was that of Hattusil II., the 'Khetasar' who made the treaty with Rameses. But we know from Babylonian, Assyrian, and Egyptian records that both before and after these kings, the Hatti were a power in Western Asia, and we have to credit them with a history of at least a thousand years. The tablets show that Subbiluliuma extended Cappadocian power over North Syria and even over great part of Mesopotamia, where the Mitanni had formerly been dominant; and that this wide dominion, extending even to the Babylonian frontier, was preserved by his chief successors, Mursil and Mutallu, and not lost till after the reign of Hattusil II., who treated with both Egypt and Babylon as an equal. Startling as this revelation is, we now see that without the existence of such a Hittite power the wide distribution of the Hittite monuments, civilisation, and physical type would have remained inexplicable; and we recognise in Boghaz Keui the natural focus from which these radiated over Asia Minor and Syria. But we recognise also that many of these monuments and much of the Hittite civilisation were work of other peoples than the Cappadocian Hatti—peoples who had learned of the latter and in many cases outlasted them. Other phenomena, too, are explained by the revelations at Boghaz Keui, notably the failure of the Aegean power of Crete to effect a lodgment in Asia Minor, and the long continuance of the Hittite name and fame in Syria. Moreover, they account, as nothing else can, for the Oriental influences which acted on the earliest Hellenic civilisation, especially on Ionian art and religion. For not even the early contact between the Muski-Phrygians and Assyria appears to have resulted in sufficient orientalisation in Phrygia and Lydia to explain the Greek phenomena. The real distributing agency of Orientalism was Cappadocia, whose art and religion were of the required type.

It is evident, then, that a great, if forgotten, part has been played in the relations between East and West by the civilisation which occupied so long the

whole land bridge between Asia and Europe. The long survival and great extension of Hittite influence in Syria has been illustrated by the excavations at Sinjerli and Sakje Geuzi, and by recent discoveries in the basin of the Middle Euphrates on both sides of the river. But an immense field remains to be explored, and other important sites must be thoroughly examined, notably Carchemish, Marash, and Malatia. When even one of these is dug according to the best modern methods a flood of light will be thrown on Hittite archæology; and with the help which the decipherment of the non-Babylonian Boghaz Keui tablets will afford to the decipherment of the Hittite inscriptions, already phonetically interpreted in no small measure by Sayce, the study of the Hittite civilisation will take its place in the field of scientific history.

APPENDIX.

The Fossil Flora and Fauna of the Midland Coalfields.—Report of the Committee, consisting of Dr. A. STRAHAN (*Chairman*), Dr. F. W. BENNETT (*Secretary*), Mr. H. BOLTON, Dr. A. R. DWERRYHOUSE, Dr. WHEELTON HIND, *and* Mr. B. HOBSON, *appointed to investigate the Fossil Flora and Fauna of the Midland Coalfields.*

Report on the Fossil Fauna and Flora of the Southern Portion of the Derbyshire and Nottinghamshire Coalfield. By ROBERT DOUGLASS VERNON, *B.Sc., Emmanuel College, Cambridge Exhibition of* 1851 *Research Scholar.*

Introduction.—The following preliminary report on the fossils of the southern portion of the Derbyshire and Nottinghamshire Coalfield records some of the results of my work during the past two years on the area delineated on the one-inch map, Sheet 125 (new series) of the Geological Survey, which includes that part of the coalfield south of Alfreton. The chief object of this report is to record the occurrence and distribution of the fresh-water mollusca, the fish, and the plants in the new fossil horizons described below.

Particular care has been taken to fix the exact stratigraphical horizon from which the fossils have been obtained, and in order to avoid the sources of error involved in collecting from colliery tip-heaps those collieries have been selected which work only one seam of coal. In all doubtful cases, as where two or more seams are worked at the same colliery, confirmatory evidence has been obtained by making a personal examination of the underground workings in order to locate the fossils *in situ.*

Previous Records.—No detailed account of the work of previous observers will be given here, since this has already been done for the flora by Mr. E. A. N. Arber,[1] and all the records of previous workers on the fauna may be summarised in the statement that only nine species of mollusca and eleven species of fish have been obtained.

Fossil Horizons.—The productive coal-measures of this district have a vertical thickness of more than 3,000 feet, and contain, as may be expected, a large number of fossil horizons. In so far as the fish and mollusca are concerned the underclays and sandstones are mostly barren, the cannel coals usually contain fish, whilst the shales and their associated beds and nodules of clay ironstone, locally called 'Rakes,' are the chief repository for mollusca, fish, and plants.

It must be noted, however, that the efforts of the present-day collector are restricted to the strata immediately overlying the seams of coal, and it is from such deposits that the fossils recorded below have been obtained.

[1] *Proc. Yorks. Geol. Soc.*, vol. xvii., Pt. ii., 1910, pp. 132–55.

Mode of Occurrence of the Fossils.—Both the plants and the mollusca occur in the grey shales (blue binds) and in the associated nodules of ironstone. In such deposits the mollusca are preserved as internal casts in ironstone, but in the black carbonaceous shales (black bat or bass) the shell itself is frequently present.

The fish are found as odd, scattered fragments in almost all the shales throughout the sequence; sometimes the remains become so numerous as to form thin 'bone beds' composed of comminuted bones, teeth, scales, and spines, with, on rare occasions, a more or less complete fish. These bone beds are most common in the black, fissile, carbonaceous shales which so frequently overlie, and pass laterally into, seams of coal, particularly cannel coal. It is from such bone beds that the fish about to be considered have been collected.

General Section of the Derbyshire and Nottinghamshire Coalfield showing the chief Fossil Horizons.

The distribution of the chief fossil horizons in relation to the important seams of coal, is given in the following general section (in descending order) of the coal-measure sequence:—

Strata	Approximate thickness in feet[1]	Fossil Horizon
Measures	500	
Clowne Coal		Fish bed.
Measures	330	
Mainbright Coal		Shell bed.
Measures	50	
Hazles Coal		Shell bed Fish bed
Measures	350	
Top Hard Coal		Shell bed.
Measures	80	
Dunsil Coal		Shell bed.
Measures	10	
Waterloo Coal		
Measures	300	
Ell Coal		
Measures	40	
Deep Soft Coal		Shell bed. Fish bed.
Measures	80	
Deep Hard Coal		Shell bed. Fish bed.
Measures	70	
Piper Coal		
Measures	40	
Hospital or Bottom Piper Coal		Shell bed.
Measures	100	
Furnace, Tupton or Low Main Coal		Shell bed.
Measures	150	
Blackshale Coal		Shell bed. Fish bed.
Measures	110	
Mickley Coal		
Measures	300	
Kilburn Coal		Fish bed.
Measures	440	
Naughton Coal		Shell bed. Fish bed.
Measures	130	
Alton Coal		Shell bed. Fish in marine bed.
Measures	300	
Belperlawn Coal		

[1] These figures apply to the district as a whole and not to any particular colliery.

Clowne Coal.—From the black shale roof of this coal at the Annesley Colliery the following fish remains were obtained:—

Rhizodopsis sauroides (Willm.).
Coelacanthus elegans (Newb.).
Platysomus parvulus (Young).
Elonichthys, sp.

Mainbright Coal.—From No. 1 pit of the Hucknall Torkard Colliery the following were obtained:—

MOLLUSCA.

Carbonicola aquilina (Sow.).
,, *subconstricta* (Sow.).
Naiadites modiolaris (Sow.).
Anthracomya Williamsoni (Brown).

PLANTS.

Neuropteris heterophylla (Brongn.).
Calamites, sp.
Calamocladus, sp.
Lepidodendron, sp.

FISH.

Diplodus gibbosus (Agass.), tooth.

Hazles Coal.—At the Gedling Colliery the roof of this seam is a prolific horizon for fossils, as the following lists show:—

MOLLUSCA.

Carbonicola acuta ? (Sow.).
,, *aquilina* (Sow.).
,, *turgida* (Brown).
,, *obtusa* (Hind).
,, *subconstricta* (Sow.).

All the species are common and the shells frequently have the periostracum preserved. The specimens of *C. aquilina* belong to a widely spread and well-known variety of the species; they are similar to those figured by Dr. Wheelton Hind from the Moss coal of the North Staffordshire Coalfield.

FISH.

Acanthodes Wardi (Egert.), fin spines, palato-quadrate, scales.
Rhizodopsis sauroides (Willm.), scales, vertebræ, maxillæ with teeth.
Diplodus gibbosus (Agass.), teeth.
Megalichthys Hibberti (Agass.), teeth, body scales.
Coelacanthus elegans (Newb.), scales, gular plate, operculum.
Pleuroplax Rankinei (Agass.), teeth, spines.
Strepsodus sauroides (Binney), teeth.
Platysomus parvulus (Young), scales.
Elonichthys Aitkeni (Traq.), scales.

This fish bed appears to be present in the roof of hazle coal of the Hucknall Colliery, from which a few fragments were obtained including:—

Rhizodopsis sauroides (Binney), scales and vertebræ.
Diplodus gibbosus (Agass.), teeth.
Megalichthys Hibberti (Agass.), scales.
Elonichthys, sp., scales.

PLANTS.

The following plants were obtained from this horizon:—

	Colliery.	
	Gedling	Hucknall Torkard
Calamites varians (Sternb.),	Gedling	
,, *cisti* (Brongn.),	,,	
,, sp.	,,	
Neuropteris obliqua (Brongn.),	,,	Hucknall Torkard
,, sp.	,,	,, ,,
Lepidophloios laricinus (Sternb.),	,,	,, ,,
Lepidodendron obovatum (Sternb.),	,,	,, ,,
,, *lycopodioides* (Sternb.),	,,	
,, *ophiurus* (Brongn.),	,,	,, ,,
,, *dichotomum* (Sternb.),	,,	,, ,,
Lepidostrobus, sp.	,,	,, ,,
Sigillaria laevigata (Brongn.),	,,	
,, *ovata* (Sauveur),	,,	

Specimens of Lepidodendron are the only common plants at this horizon.

Top Hard Coal (Barnsley Bed).—In discussing the molluscan assemblage found in association with this seam an experimental area of about 40 square miles will be considered; its boundaries are fixed on the west by the almost continuous outcrop of the coal from Wollaton, near Nottingham, to Pinxton, a distance of ten miles, and on the east by the line of collieries from Gedling up the Leen Valley to Annesley. Within this area the fossil horizon has been detected in the three good exposures on the outcrop of the seam:—

Digby clay pits. Level at Brookhill Leys.
Clay pit at Stoney Lane, Brinsley.

and also at the following eight collieries:—

Gedling.	Annesley.
Bestwood.	Bulwell.
Hucknall Torkard.	New Watnall.
Newstead.	High Park.

There is thus every reason to infer that this fossil horizon extends continuously throughout and beyond the area under consideration. The following general section of the roof of the Top Hard Coal illustrates the mode of occurrence of the fossils:—

Grey shale with bands and nodules of ironstone, numerous *shells*.
Combe Coal.
Underclay (clunch) passing laterally into shale with *shells*.
Top Hard Coal.

The following lists enumerate the fossils from this horizon:—

MOLLUSCA.

Naiadites modiolaris (Sow.).	*Carbonicola aquilina* (Sow.).
,, *carinata* (Sow.).	,, *similis* (Brown).
,, *triangularis* (Sow.).	,, *nucularis* (Hind.).
,, *quadrata* (Sow.).	*Anthracomya modiolaris* (Sow.).
	,, *Williamsoni* (Brown).

FISH.

Coelacanthus elegans (Newb.), a solitary scale; Gedling Colliery.

PLANTS.

	Colliery.	
Calamites suckowii (Brongn.),	Newstead	—
,, *varians* (Sternb.),	—	Gedling
Sphenophyllum cuneifolium, var. *saxifragaefolium* (Sternb.),	—	,,
Neuropteris gigantea (Sternb.),	Newstead	—
,, *heterophylla* (Brongn.),	,,	Gedling
,, *obliqua* (Brongn.),	,,	,,
,, *tenuifolia* (Schl.),	—	,,
Alethopteris lonchitica (Schl.),	Newstead	,,
Mariopteris muricata (Schl.),	,,	—
,, *latifolia* (Brongn.),	,,	Gedling
Sigillaria laevigata (Brongn.),	,,	—
,, *rugosa* (Brongn.),	—	Hucknall Torkard
Lepidodendron aculeatum (Sternb.),	Newstead	,,
Lepidophyllum lancifolium (Lesq.),	—	Gedling
,, cp. *intermedium*,	—	,,
Lepidostrobus, sp.,	Newstead	,,
Stigmaria ficoides,	,,	,,
Pinnularia, sp.,	—	,,
Trigonocarpus Parkinsoni (Brongn.),	Newstead	,,

Between the Top Hard Coal and the Deep Soft Coal exposures are scarce, consequently the number of fossil horizons known from these intermediate measures are few.

Ninety-eight yards below the Top Hard Coal.—During the sinking of the new shaft to the Blackshale Coal at the Pinxton Colliery a prolific fish-bed was discovered in a black shale or impure cannel coal at this depth, which contained the following fossils:—

FISH.

Acanthodes Wardi (Egert.), fin spines.
Rhizodopsis sauroides (Willm.), scales, and excepting the head a nearly complete fish.
Coelacanthus elegans (Newb.), scales, jugular plate.
Megalichthys Hibberti (Agass.), scales, teeth, mandible with teeth.
Diplodus gibbosus (Agass.), teeth.
Platysomus parvulus (Young.), scales.
Elonichthys, sp., scales.

The following plants were also obtained at about the same depth:—

PLANTS.

Pecopteris Miltoni (Artis.).
Neuropteris gigantea (Sternb.).
,, *obliqua* (Brong.).

Seventy yards above the Deep Soft Coal.—From an exposure on this horizon in the Midland Railway cutting at Pyebridge, Dr. L. Moysey, of Nottingham, has kindly sent me a number of shells, including the following.

MOLLUSCA.

Carbonicola turgida (Brown.).
,, *aquilina* (Sow.).
,, *subconstricta* (Sow.).
Naiadites modiolaris (Sow.).
Anthracomya modiolaris (Sow.).
,, *Williamsoni* (Brown).

C. turgida and *A. modiolaris* are here the most common forms. The shells occur in black shales and have the periostracum preserved.

Fifty yards above the Deep Soft Coal.—An exposure at Messrs. Oakes and Co.'s clay pit at Pyehill contains numerous shells, chiefly in the ironstone nodules from certain grey shales. The following were obtained:—

MOLLUSCA.

Carbonicola aquilina (Sow.).
„ *turgida* (?) (Brown).
„ *nucularis* (Hind.).
Naiadites modiolaris (Sow.).
Anthracomya modiolaris (Sow.).

The fossils are all in the condition of internal casts in ironstone; *C. aquilina* and *A. modiolaris* being the only common species.

Deep Soft Coal.—At Cinderhill Colliery the black shale roof of this coal contains crushed shells, including:—

MOLLUSCA.

Carbonicola aquilina (Sow.).
„ *subconstricta* (Sow.).

as well as fish remains, including:—

FISH.

Rhizodopsis sauroides (Willm.).
Coelacanthus elegans (Newb.).
Megalichthys Hibberti (Agass.).

Deep Hard Coal.—At the Radford Colliery a heavy, black fissile shale, said to form the floor of the seam, is rich in fish, as the following list shows:—

Acanthodes Wardi (Egert.), fin spines.
Megalichthys Hibberti (Agass.), teeth, scales.
Platysomus parvulus (Young), scales
Rhizodopsis sauroides (Willm.), scales, vertebræ.
Coelacanthus elegans (Newb.), scales.
Rhadinichthys Wardi (?) (Ward), scales.
Cheirodus granulosus (Young), palatal dentigerous bone.
Elonichthys Egertoni (Egert.), scales.

Deep Soft and Deep Hard Coal.—In both these seams, at the parting between the coal and the roof, and more rarely in the seam itself, large fish remains, especially ichthyodorulites, are sometimes found.

This horizon was discovered by Mr. T. G. Lees, manager of Newstead Colliery, in the workings of the Clifton Colliery. His collection includes the following species:—

Gyracanthus formosus (Agass.), spines.
Ctenacanthus, sp., spines.
Strepsodus sauroides (Binney), tooth.
Megalichthys Hibberti (Agass.), teeth, scales, vertebrae.

This horizon also occurs at the Radford Colliery, where the same species have been obtained. In each case the remains are very much larger in size than those from any other fish-bed in this district.

At Radford Colliery the roof shales of these coals contain shells, including the following:—

Anthracomya modiolaris (Sow.).
Naiadites carinata (Sow.).
Carbonicola nucularis (Hind).

Many of these shells, especially the specimens of *C. nucularis*, are infested with numerous spirorbis.

At the Waingroves Colliery, Cross Hills, near Heanor, certain ironstone nodules, probably from below the Deep Soft Coal, contained the following shells:—

Carbonicola acuta (Sow.).
,, *ovalis* (Martin).

A fish-bearing cannel coal, probably from the Deep Soft seam, contained the following:—

Rhizodopsis sauroides (Willm.).
Coelacanthus elegans (Newb.).
Megalichthys Hibberti (Agass.).

Furnace Coal.—This seam is exposed in the floor of a brick pit close to the canal, near Cossall Marsh, Ilkeston. From the black roof shales of the coal, and from the overlying grey shales with ironstone nodules, the following fossils were obtained:—

MOLLUSCA.

Carbonicola acuta (Sow.).
,, *acuta*, var. *rhomboidalis* (Hind).
,, *aquilina* (Sow.).
,, *turgida* (Brown).
,, *nucularis* (Hind).
,, *robusta* (Sow.).
Naiadites modiolaris (Sow.).

Black Shale Coal.—At the Pinxton Colliery the black roof shales of this seam contain fish remains, but it is characterised by a profusion of shells, *Carbonicola robusta* being the most common. The assemblage includes the following species of mollusca:—

Carbonicola robusta (Sow.).
,, *nucularis* (Hind).
,, *aquilina* (Sow.).
,, *turgida* (Brown).
Naiadites, sp.

This horizon, which extends over a large area, is of special interest on account of the large size to which the specimens of Naiadites attain. All the fossils have the shell substances preserved, and, although frequently crushed, the hinge area is often clearly seen.

The same coal at the Pyehill Colliery yielded the following plants:—

Alethopteris lonchitica (Schl.).
,, *valida* (Bonlay).
Lepidodendron Wortheni (Lesq.).
Trigonocarpus, sp.
Cordaianthus Pitcairniae (L. and H.).

Sixty yards above the Kilburn Coal.—Between the Blackshale Coal and the Kilburn Coal exposures are scarce. A brick pit at the Albany, north of Stapleford, shows a thin coal about 60 yards above the Kilburn Coal. From the ironstone nodules in the black shales overlying the coal the following mollusca have been obtained:—

Naiadites modiolaris (Sow.).
Carbonicola aquilina (Sow.).
„ *robusta* (Sow.).

In addition, a solitary scale of *Coelacanthus elegans* (Newb.) was found. The floor of the brick pit is a very hard, massive, ripple-marked bed of ganister-like sandstone containing numerous specimens of *Carbonicola aquilina*. This is the first occasion known to the writer of the occurrence of the mud-loving genus Carbonicola in an arenaceous rock.

Kilburn Coal.—The Survey record a fish-bed from the roof of this coal at the Denby Colliery.

At the Horsley, Dale Abbey, Stanley, and Mapperley Collieries the black roof shales of this coal also contain fish remains. The list, which is still incomplete, includes the following:—

Megalichthys Hibberti (Agass.).
Rhizodopsis sauroides (Willm.).
Sphenacanthus hybodoides (Egert.).
Acanthodes Wardi (Egert.).
Elonichthys Egertoni (Egert.).
Coelacanthus elegans (Newb.).

At the Trowell Moor Colliery a few shells occur, including:—

Carbonicola similis.
Naiadites modiolaris.

The specimens of *C. similis* are identical in condition and size with those recorded from the Top Hard Coal.

The roof shales of the Kilburn Coal in the new sinking at Loscoe Colliery, near Heanor, yielded a number of shells, including:—

Carbonicola robusta (Sow.).
„ *aquilina* (Sow.).

Honeycroft Rake.—In the Stanton district, on the outcrop of the Kilburn Coal, the abandoned open-cast workings in this rake contain specimens of *Carbonicola robusta* (Sow.).

The roof shales of the Trowell Moor Colliery yielded the following plants:—

Calamites cistii (Brongn.).
„ *ramosus* (Artis).
„ sp. (external surface).
Sphenophyllum cuneifolium (Sternb.).
Alethopteris lonchitica (Schl.).
Mariopteris latifolia (Brongn.).
„ sp.
Neuropteris heterophylla (Brongn.).
„ *obliqua* (Brongn.).
Aphlebia crispa (Gutbier).
Lepidophyllum lancifolius (Lesq.).
Stigmaria ficoides.
Pinnularia, sp.

Ten yards above the Naughton Coal.—From this horizon a persistent shell bed in the Ilkeston district has yielded the following list:—

Carbonicola acuta (Sow.).
  „ *acuta*, var. *rhomboidalis* (Hind).
  „ *aquilina* (Sow.).
  „ *nucularis* (Hind).
  „ *robusta* (Sow.).
Naiadites modiolaris (Sow.).
Anthracomya modiolaris (Sow.).
  „ *laevis*, var. *scotica* (R. Eth., junr.).

Carbonicola acuta and *C. aquilina* were the most abundant species.

Naughton Coal.—It has not been possible to add to the list of fish remains recorded by the Survey from the roof of this coal at the Kilburn Colliery, although the fish-bed has been found to occur on the outcrop of the coal on Dale Moor, near Stanton.

Dale Moor Rake.—Some fifty years ago the 'bottom balls' of this rake in the workings near Stanton yielded a large number of entire fishes in an excellent state of preservation. A number of these, including several type specimens, are preserved in the Museum of the Geological Survey, in the British Museum, and in the Binney collection at the Sedgwick Museum, Cambridge.

The complete list is given below for the purpose of comparison with the lists from other fish-beds higher in the sequence:—

Rhizodopsis sauroides (Willm.).
Coelacanthus elegans (Newb.).
Platysomus tenuistriatus (Traq.).
Elonichthys Aitkeni (Traq.).
  „ *Binneyi* (Traq.).
Mesolepis Wardi (Young).
  „ *microptera* (Traq.).
  „ *scalaris* (Young).

Alton Coal.—The marine bed roof of this coal contains fish remains, both in the shale and in the pyritous nodules. Specimens have been collected from the following localities—the trial sinking at the Oakwell Colliery, Ilkeston, the abandoned colliery at Alton, and the outcrop of the seam at the Bullbridge brick pit at Ambergate.

The list, which is incomplete, includes the following:—

Hoplonchus, sp.
Rhizodopsis sauroides (Willm.).
Rhadinichthys monensis (Egert.).
Megalichthys intermedius (A. S. Woodw.).
  „ *Hibberti* (Agass.).
Elonichthys Egertoni (Egert.).
  „ sp.
Coelacanthus (Newb.).
Acanthodes sp.

With the exception of the plants, the various lists of fossils recorded above are summarised in the following two tables in order to bring out more clearly the vertical range of each species and also the assemblage of fossils characteristic of the chief fossil horizons.

The Vertical Range of the Mollusca.—Of the twenty species of lamellibranchs recorded above, three are very common and range throughout more than 2,500 feet of strata, they are:—

Carbonicola aquilina.
,, *acuta.*
Naiadites modiolaris.

The range of the following three species is also very wide:—

Carbonicola similis.
,, *turgida.*
Anthracomya modiolaris.

C. similis occurs in the roof of the Kilburn Coal and also in the roof of the Top Hard Coal some 1,300 feet above; but, in spite of repeated search, this shell has not yet been found in the intervening measures.

Anthracomya Phillipsii appears to be restricted to the highest measures above the Top Hard Coal. The following four species have, up to the present, been found only in the middle portion of the sequence between the Mainbright Coal and the Deep Hard Coal:—

Carbonicola obtusa.
,, *subconstricta.*
,, *ovalis.*
Anthracomya Williamsoni.

The lowest measures between the Deep Hard Coal and the base of the coal-measures are characterised by the presence of the following four species:—

Carbonicola robusta.
,, *nucularis.*
,, *acuta,* var. *rhomboidalis.*
Anthracomya laevis, var. *scotica.*

In addition to the species of mollusca recorded above, it has been observed that several intermediate varieties, showing gradational forms between two or more species, are by no means rare.

TABLE I.

List of Fish Remains from the Chief Fish Beds.

Species	Clowne Coal	Hazle Coal	98 yards below Top Hard Coal	Deep Soft Coal	Deep Hard Coal	Kilburn Coal	Naughton Coal	Dale Moor Rake	Alton Coal
ELASMOBRANCHII.									
I.—ACANTHODII.									
Acanthodes Wardi (Egert.)	—	×	×	—	×	×	—	—	—
,, sp.	—	—	—	—	—	—	—	—	×
II.—ICHTHYOTOMI.									
Diplodus gibbosus (Agass.)	—	×	×	—	—	—	—	—	—
III.—SELACHII.									
Pleuroplax Rankenei (Agass.)	—	×	—	—	—	—	—	—	—
Sphenacanthus hybodoides (Egert.)	—	—	—	—	—	×	—	—	—
IV.—ICHTHYODORULITES.									
Gyracanthus formosus (Agass.)	—	—	—	×	×	—	—	—	—
Ctenacanthus, sp.	—	—	—	×	×	—	—	—	—
Hoplonchus, sp.	—	—	—	—	—	—	—	—	×
TELEOSTOMI.									
I.—CROSSOPTERYGII.									
Coelacanthus elegans (Newt.)	×	×	×	×	×	×	×	×	×
Megalichthys Hibberti (Agass.)	—	×	×	×	×	×	—	—	×
,, *intermedius* (A. S. Woodw.)	—	—	—	—	—	—	—	—	×
Rhizodopsis sauroides (Willm.)	×	×	×	×	×	×	×	×	×
Strepsodus sauroides (Binney)	—	×	—	×	×	—	—	—	—
II.—ACTINOPTERYGII.									
Rhadinichthys monensis (Egert.)	—	—	—	—	—	—	—	—	×
,, *Wardi* (Warde)	—	—	—	—	×	—	—	—	—
Elonichthys Aitkeni (Traq.)	—	×	—	—	—	—	—	×	—
,, *Binneyi* (Traq.)	—	—	—	—	—	—	—	×	—
,, *Egertoni* (Egert.)	—	—	—	—	×	×	—	—	×
,, sp.	×	×	×	—	—	—	—	—	×
Mesolepis Wardi (Young)	—	—	—	—	—	—	—	×	—
,, *microptera* (Traq.)	—	—	—	—	—	—	—	×	—
,, *scalaris* (Young)	—	—	—	—	—	—	—	×	—
Cheirodus granulosus (Young)	—	—	—	—	×	—	—	—	—
Platysomus parvulus (Young)	×	×	×	—	×	—	—	—	—
,, *tenuistriatus* (Traq.)	—	—	—	—	—	—	—	×	—

TABLE II.

List of Lamellibranchiata from the Chief Shell Beds.

Species	Above the Clowne Coal	Mainbright Coal	Hazle Coal	Top Hard Coal	Dunsil Coal	70 yards above the Deep Soft Coal	50 yards above the Deep Hard Coal	Deep Soft Coal Deep Hard Coal	Hospital Coal	Furnace Coal	Black Shale Coal	60 yards above the Kilburn Coal	Kilburn Coal	Honeycroft Rake	10 yards above the Naughton Coal	Above the Alton Coal	10 yards below the Alton Coal
Naiadites carinata (Sow.)	—	—	—	×	—	—	—	×	—	—	—	—	—	—	—	—	—
„ *modiolaris* (Sow.)	—	×	—	×	×	×	×	—	—	×	—	×	×	—	×	—	—
„ *quadrata* (Sow.)	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—
„ *triangularis* (Sow.)	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—
„ sp.	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—
Anthracomya Phillipsii (Willm.)	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
„ *calcifera*	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
„ *modiolaris* (Sow.)	—	—	—	×	×	×	×	×	—	—	—	—	—	—	×	—	—
„ *Williamsoni* (Brown)	—	×	—	×	—	×	—	—	—	—	—	—	—	—	—	—	—
„ *laevis*, var. *scotica* (Dawson)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	×	—
Carbonicola aquilina (Sow.)	—	×	×	×	×	×	×	×	—	×	×	×	×	—	×	—	—
„ *acuta* (Sow.)	—	—	×	—	—	—	—	×	—	×	—	—	—	—	×	×	—
„ *acuta*, var. *rhomboidalis* (Hind.)	—	—	—	—	—	—	—	—	—	×	—	—	—	—	×	—	—
„ *nucularis* (Hind)	—	—	—	×	—	—	×	×	—	×	×	—	—	—	×	—	—
„ *robusta* (Sow.)	—	—	—	—	—	—	—	—	×	×	×	×	×	×	×	—	×
„ *obtusa* (Hind)	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—
„ *ovalis* (Martin)	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—
„ *subconstricta* (Sow.)	—	×	×	—	—	×	—	×	—	—	—	—	—	—	—	—	—
„ *similis* (Brown)	—	—	—	×	—	—	—	—	—	—	—	—	×	—	—	—	—
„ *turgida* (Brown)	—	—	×	—	—	×	×	—	—	×	×	—	—	—	—	—	—

INDEX.

References to reports and papers printed in extenso *are given in Italics.*
*An asterisk * indicates that the title only of the communication is given.*
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ARMSTRONG, Professor H. E., F.R.S.
BOWLEY, A. L., M.A.
BROWN, Dr. HORACE T., F.R.S.
BRUNTON, Sir LAUDER, Bart., F.R.S.
CLOSE, Colonel C. F., R.E., C.M.G.
CRAIGIE, Major P. G., C.B.
CROOKE, W., B.A.
DYSON, F. W., F.R.S.
GLAZEBROOK, Dr. R. T., F.R.S.
HADDON, Dr. A. C., F.R.S.
HALL, A. D., F.R.S.
HARTLAND, E. SIDNEY, F.S.A.
MARR, Dr. J. E., F.R.S.
MITCHELL, Dr. P. CHALMERS, F.R.S.
MYRES, Professor J. L., M.A.
POULTON, Professor E. B., F.R.S.
PRAIN, Lieut.-Colonel D., C.I.E., F.R.S.
SHERRINGTON, Professor C. S., F.R.S.
SHIPLEY, Dr. A. E., F.R.S.
TEALL, J. J. H., F.R.S.
THOMPSON, Dr. SILVANUS P., F.R.S.
TUTTON, Dr. A. E. H., F.R.S.
WHITE, Sir W. H., K.C.B., F.R.S.

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The Trustees, past Presidents of the Association, the President and Vice-Presidents for the year, the President and Vice-Presidents Elect, past and present General Treasurers and General Secretaries, past-Assistant General Secretaries, and the Local Treasurers and Local Secretaries for the ensuing Annual Meeting.

TRUSTEES (PERMANENT).

The Right Hon. Lord AVEBURY, D.C.L., LL.D., F.R.S., F.L.S.
The Right Hon. Lord RAYLEIGH, M.A., D.C.L., LL.D., F.R.S., F.R.A.S.
Sir ARTHUR W. RÜCKER, M.A., D.Sc., LL.D., F.R.S.

PAST PRESIDENTS OF THE ASSOCIATION.

Sir Joseph D. Hooker, G.C.S.I.
Lord Avebury, D.C.L., F.R.S.
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Sir William Crookes, O.M., F.R.S.
Sir W. Turner, K.C.B., F.R.S.
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Sir Norman Lockyer, K.C.B., F.R.S.
Arthur J. Balfour, D.C.L., F.R.S.
Sir George Darwin, K.C.B., F.R.S.
Sir E. Ray Lankester, K.C.B., F.R.S.
Sir David Gill, K.C.B., F.R.S.
Dr. Francis Darwin, F.R.S.
Sir J. J. Thomson, F.R.S.

PAST GENERAL OFFICERS OF THE ASSOCIATION.

Sir F. Galton, D.C.L., F.R.S.
P. L. Sclater, Ph.D., F.R.S.
Prof. T. G. Bonney, Sc.D., F.R.S.
A. Vernon Harcourt, F.R.S.
Sir A. W. Rücker, D.Sc., F.R.S.
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Dr. D. H. Scott, M.A., F.R.S.
Dr. G. Carey Foster, F.R.S.
Dr. J. G. Garson.

AUDITORS.

Sir Edward Brabrook, C.B.
Professor H. McLeod, F.R.S.

LIST OF MEMBERS

OF THE

BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

1910.

* indicates Life Members entitled to the Annual Report.
§ indicates Annual Subscribers entitled to the Annual Report.
‡ indicates Subscribers not entitled to the Annual Report.
Names without any mark before them are Life Members, elected before 1845, not entitled to the Annual Report.
Names of Members of the GENERAL COMMITTEE are printed in SMALL CAPITALS.
Names of Members whose addresses are incomplete or not known are in *italics*.

Notice of changes of residence should be sent to the Assistant Secretary, Burlington House, London, W.

Year of Election.

1905. *à-Ababrelton, Robert, F.R.G.S., F.S.S. P.O. Box 322, Pietermaritzburg, Natal. Care of Royal Colonial Institute, Northumberland-avenue, W.C.
1887. *ABBE, Professor CLEVELAND. Local Office, U.S.A. Weather Bureau, Washington, U.S.A.
1881. *Abbott, R. T. G. Whitley House, Malton.
1885. *ABERDEEN, The Earl of, G.C.M.G., LL.D. Haddo House, Aberdeen.
1885. ‡Aberdeen, The Countess of. Haddo House, Aberdeen.
1873. *ABNEY, Captain Sir W. DE W., K.C.B., D.C.L., F.R.S., F.R.A.S. (Pres. A, 1889; Pres. L, 1903; Council, 1884–89, 1902–05, 1906– .) Measham Hall, Leicestershire.
1905. ‡Abrahamson, Louis. Civil Service Club, Cape Town.
1905. §Aburrow, Charles. P.O. Box 534, Johannesburg.
1882. **Acland, Alfred Dyke.* *38 Pont-street, Chelsea, S.W.*
1869. ‡Acland, Sir C. T. Dyke, Bart., M.A. Killerton, Exeter.
1877. *Acland, Captain Francis E. Dyke, R.A. Walwood, Banstead, Surrey.
1894. *ACLAND, HENRY DYKE, F.G.S. Lamorva, Falmouth.
1877. *Acland, Theodore Dyke, M.D. 19 Bryanston-square, W.
1904. ‡Acton, T. A. 3 Grove-road, Wrexham.

Year of Election

1898. ‡Acworth, W. M., M.A. (Pres. F, 1908.) The Albany, W.
1901. ‡Adam, J. Miller. 15 Walmer-crescent, Glasgow.
1887. ‡Adami, J. G., M.A., M D., F.R.S., Professor of Pathology in McGill University, Montreal, Canada.
1901. §Adams, John, M.A., Professor of Education in the University of London. 23 Tanza-road, Hampstead, N.W.
1904. ‡Adams, W. G. S., M.A. Department of Agriculture, Upper Merrion-street, Dublin.
1869. *Adams, William Grylls, M.A., D.Sc., F.R.S., F.G.S., F.C.P.S. (Pres. A, 1880; Council, 1878–85.) Heathfield, Broadstone, Dorset.
1908. §Adamson, R. Stephen. Emmanuel College, Cambridge.
1898. ‡Addison, William L. T. Byng Inlet, Ontario, Canada.
1890. ‡Adeney, W. E., D.Sc., F.C.S. Royal University of Ireland, Earlsfort-terrace, Dublin.
1899. *Adie, R. H., M.A., B.Sc. 136 Huntingdon-road, Cambridge.
1908. §Adkin, Robert. 4 Lingard's-road, Lewisham, S.E.
1905. ‡Adle, Henry. P.O. Box 1059, Johannesburg.
1908. *Agar, W. E., M.A. Natural History Department, The University, Glasgow.
1902. ‡Agnew, Samuel, M.D. Bengal-place, Lurgan.
1909. ‡Aikins, J. Somerset. 426 Assiniboine-avenue, Winnipeg, Canada.
1906. §Aikman, J. A. 6 Glencairn-crescent, Edinburgh.
1871. *Ainsworth, John Stirling. Harecroft, Gosforth, Cumberland.
1909. *Aird, John. Canadian Bank of Commerce, Winnipeg, Canada.
1890. *Airedale, Lord. Gledhow Hall, Leeds.
1895. *Airy, Hubert, M.D. Stoke House, Woodbridge, Suffolk.
1891. *Aisbitt, M. W. Mountstuart-square, Cardiff.
1871. §Aitken, John, LL.D., F.R.S., F.R.S.E. Ardenlea, Falkirk, N.B.
1901. ‡Aitken, Thomas, M.Inst.C.E. County Buildings, Cupar-Fife.
1884. *Alabaster, H. Milton, Grange-road, Sutton, Surrey.
1886. *Albright, G. S. Broomsberrow Place, Ledbury.
1905. ‡Albright, Miss. Finstal Farm, Finstal, Bromsgrove, Worcestershire.
1907. ‡Alcock, N. H., M.D., D.Sc. 22 Downshire-hill, Hampstead, N.W.
1910. §Alderson, Miss E. M. Park House, Worksop.
1900. *Aldren, Francis J., M.A. The Lizans, Malvern Link.
1896. §Aldridge, J. G. W., Assoc.M.Inst.C.E. 39 Victoria-street, Westminster, S.W.
1905. *Alexander, J. Abercromby, F.S.A. 24 Lawn-crescent, Kew.
1888. *Alexander, Patrick Y. 2 Whitehall-court, S.W.
1910. §Alexander, W. B., B.A. King's College, Cambridge.
1891. *Alford, Charles J., F.G.S. Hôtel Angleterre, Vevey, Switzerland.
1883. ‡Alger, W. H. The Manor House, Stoke Damerel, South Devon.
1883. ‡Alger, Mrs. W. H. The Manor House, Stoke Damerel, South Devon.
1901. *Allan, James A. 21 Bothwell-street, Glasgow.
1904. *Allcock, William Burt. Emmanuel College, Cambridge.
1879. *Allen, Rev. A. J. C. 34 Lensfield-road, Cambridge.
1898. §Allen, Dr. E. J. The Laboratory, Citadel Hill, Plymouth.
1907. *Allorge, M. M., L. ès Sc., F.G.S. University Museum, Oxford.
1882. *Alverstone, The Right Hon. Lord, G.C.M.G., LL.D., F.R.S. Hornton Lodge, Hornton-street, Kensington, W.
1887. ‡Alward, G. L. Enfield Villa, Waltham, Grimsby, Yorkshire.
1883. §Amery, John Sparke. Druid, Ashburton, Devon.
1884. ‡Ami, Henry, M.A., D.Sc., F.G.S. Geological Survey, Ottawa, Canada.

Year of Election.

1909. ‡Ami, H. M., M.D. Ottawa, Canada.
1905. ‡Anderson, A. J., M.A., M.B. The Residency, Portswood-road, Green Point, Cape Colony.
1910. §Anderson, Alexander. The University, Glasgow.
1905. *Anderson, C. L. P.O. Box 2162, Johannesburg.
1908. ‡Anderson, Edgar. Glenavon, Merrion-road, Dublin.
1885. *ANDERSON, HUGH KERR, M.A., M.D., F.R.S. Caius College, Cambridge.
1901. *Anderson, James. 10 Albion-crescent, Dowanhill, Glasgow.
1892. ‡Anderson, Joseph, LL.D. 8 Great King-street, Edinburgh.
1899. *Anderson, Miss Mary Kerr. 13 Napier-road, Edinburgh.
1888. *Anderson, R. Bruce. 5 Westminster-chambers, S.W.
1887. ‡ANDERSON, Professor R. J., M.D., F.L.S. Queen's College, and Atlantic Lodge, Salthill, Galway.
1905. ‡Anderson, T. J. P.O. Box 173, Cape Town.
1880. *ANDERSON, TEMPEST, M.D., D.Sc., F.G.S. (Council, 1907– ; Local Sec. 1881.) 17 Stonegate, York.
1901. *Anderson, Dr. W. Carrick. 7 Scott-street, Garnethill, Glasgow.
1908 ‡Anderson, William. Glenavon, Merrion-road, Dublin.
1907. ‡Andrews, A. W. Adela-avenue, West Barnes-lane, New Malden, Surrey.
1909. ‡Andrews, Alfred J. Care of Messrs. Andrews, Andrews, & Co., Winnipeg, Canada.
1895. ‡Andrews, Charles W., B.A., D.Sc., F.R.S. British Museum (Natural History), S.W.
1909. ‡Andrews, G. W. 433 Main-street, Winnipeg, Canada.
1880. *Andrews, Thornton, M.Inst.C.E. Cefn Eithen, Swansea.
1886. §Andrews, William, F.G.S. Steeple Croft, Coventry.
1877. §ANGELL, JOHN, F.C.S., F.I.C. 6 Beacons-field, Derby-road, Withington, Manchester.
1900. ‡Annandale, Nelson. 34 Charlotte-square, Edinburgh.
1896. ‡Annett, R. C. F., Assoc.Inst.C.E. 4 Buckingham-avenue, Sefton Park, Liverpool.
1886. ‡Ansell, Joseph. 27 Bennett's-hill, Birmingham.
1890. ‡Antrobus, J. Coutts. Eaton Hall, Congleton.
1901. ‡Arakawa, Minozi. Japanese Consulate, 84 Bishopsgate-street Within, E.C.
1900. ‡Arber, E. A. Newell, M.A., F.L.S. Trinity College, Cambridge.
1904. *Arber, Mrs. E. A. Newell, D.Sc. 52 Huntingdon-road, Cambridge.
1894. ‡Archibald, A. Holmer, Court-road, Tunbridge Wells.
1884. *Archibald, E. Douglas. Constitutional Club, W.C.
1909. §Archibald, Professor E. H. Bowne Hall of Chemistry, Syracuse University, Syracuse, New York, U.S.A.
1909. §Archibald, H. Care of Messrs. Machray, Sharpe, & Dennistoun, Bank of Ottawa Chambers, Winnipeg, Canada.
1883. *Armistead, William. Hillcrest, Oaken, Wolverhampton.
1908. ‡Armstrong, E. C. R., M.R.I.A., F.R.G.S. Cyprus, Eglinton-road, Dublin.
1903. *ARMSTRONG, E. FRANKLAND, D.Sc., Ph.D. 98 London-road, Reading.
1873. *ARMSTRONG, HENRY E., Ph.D., LL.D., F.R.S. (Pres. B, 1885, 1909; Pres. L, 1902; Council, 1899–1905, 1909–), Professor of Chemistry in the City and Guilds of London Institute, Central Institution, Exhibition-road, S.W. 55 Granville-park, Lewisham, S.E.
1909. ‡Armstrong, Hon. Hugh. Parliament Buildings, Kennedy-street, Winnipeg, Canada.

Year of Election.

1905. ‡Armstrong, John. Kamfersdam Mine, near Kimberley, Cape Colony.
1905. §Arnold, J. O., Professor of Metallurgy in the University of Sheffield.
1893. *Arnold-Bemrose, H. H., Sc.D., F.G.S. Ash Tree House, Osmaston-road, Derby.
1904. ‡Arunachalam, P. Ceylon Civil Service, Colombo, Ceylon.
1870. *Ash, Dr. T. Linnington. Penroses, Holsworthy, North Devon.
1903. *Ashby, Thomas. The British School, Rome.
1909. ‡Ashdown, J. H. 337 Broadway, Winnipeg, Canada.
1907. ‡Ashley, W. J., M.A. (Pres. F, 1907), Professor of Commerce in the University of Birmingham. 3 Yateley-road, Edgbaston, Birmingham.
Ashworth, Henry. Turton, near Bolton.
1903. *Ashworth, J. H., D.Sc. 4 Cluny-terrace, Edinburgh.
1890. ‡Ashworth, J. Reginald, D.Sc. 105 Freehold-street, Rochdale.
1905. ‡Askew, T. A. Main-road, Claremont, Cape Colony.
1875. *Aspland, W. Gaskell. 50 Park Hill-road, N.W.
1896. *Assheton, Richard, M.A., F.L.S. Grantchester, Cambridge.
1905. ‡Assheton, Mrs. Grantchester, Cambridge.
1908. §Astley, Rev. H. J. Dukinfield, M.A., Litt.D. East Rudham Vicarage, King's Lynn.
1903. ‡Atchison, Arthur F. T., B.Sc. Royal Engineering College, Cooper's Hill, Staines.
1887. §Atkinson, Rev. C. Chetwynd, D.D. Ashton-on-Mersey Rectory, Cheshire.
1898. *Atkinson, E. Cuthbert. 5 Pembroke-vale, Clifton, Bristol.
1894. *Atkinson, Harold W., M.A. West View, Eastbury-avenue, Northwood, Middlesex.
1906. ‡Atkinson, J. J. Cosgrove Priory, Stony Stratford.
1881. ‡Atkinson, J. T. The Quay, Selby, Yorkshire.
1907. ‡Atkinson, Robert E. Morland-avenue, Knighton, Leicester.
1881. ‡Atkinson, Robert William, F.C.S., F.I.C. (Local Sec. 1891.) 44 Loudoun-square, Cardiff.
1863. *Attfield, J., M.A., Ph.D., F.R.S., F.C.S. Ashlands, Watford, Herts.
1906. §Auden, G. A., M.A., M.D. The Education Office, Edmund-street, Birmingham.
1907. §Auden, H. A., D.Sc. 13 Broughton-drive, Grassendale, Liverpool.
1903. ‡Austin, Charles E. 37 Cambridge-road, Southport.
1853. *Avebury, The Right Hon. Lord, D.C.L., F.R.S. (President, 1881; Trustee, 1872– ; Pres. D, 1872; Council, 1865–71.) High Elms, Farnborough, Kent.
1909. ‡Axtell, S. W. Stobart Block, Winnipeg, Canada.

1883. *Bach-Gladstone, Madame Henri. 147 Rue de Grenelle, Paris.
1906. ‡Backhouse, James. Daleside, Scarborough.
1883. *Backhouse, W. A. St. John's, Wolsingham, R.S.O., Durham.
1887. *Bacon, Thomas Walter. Ramsden Hall, Billericay, Essex.
1903. ‡Baden-Powell, Major B. 22 Prince's-gate, S.W.
1907. §Badgley, Colonel W. F., Assoc.Inst.C.E., F.R.G.S. Verecroft, Devizes.
1908. *Bagnall, Richard Siddoway. Penshaw Lodge, Penshaw, Co. Durham.
1905. ‡Baikie, Robert. P.O. Box 36, Pretoria, South Africa.
1883. ‡Baildon, Dr. 42 Hoghton-street, Southport.
1883. *Bailey, Charles, M.Sc., F.L.S. Haymesgarth, Cleeve Hill S.O., Gloucestershire.

Year of Election.

1893. ‡BAILEY, Colonel F., F.R.G.S. 7 Drummond-place, Edinburgh.
1887. *Bailey, G. H., D.Sc., Ph.D. Edenmor, Kinlochleven, Argyll, N.B.
1905. *Bailey, Harry Percy. 46 Arundel-gardens, W.
1905. ‡Bailey, Right Hon. W. F., C.B. Land Commission, Dublin.
1894. *BAILY, FRANCIS GIBSON, M.A. Newbury, Colinton, Midlothian.
1878. ‡BAILY, WALTER. 4 Roslyn-hill, Hampstead, N.W.
1905. *Baker, Sir Augustine. 56 Merrion-square, Dublin.
1910. §Baker, H. F., Sc.D., F.R.S. St. John's College, Cambridge.
1886. §Baker, Harry, F.I.C. Epworth House, Moughland-lane, Runcorn.
1907. ‡Baldwin, Walter. 5 St. Alban's-street, Rochdale.
1904. ‡BALFOUR, The Right Hon. A. J., D.C.L., LL.D., M.P., F.R.S., Chancellor of the University of Edinburgh. (PRESIDENT, 1904.) Whittingehame, Prestonkirk, N.B.
1894. ‡BALFOUR, HENRY, M.A. (Pres. H, 1904.) Langley Lodge, Headington Hill, Oxford.
1905. ‡Balfour, Mrs. H. Langley Lodge, Headington Hill, Oxford.
1875. ‡BALFOUR, ISAAC BAYLEY, M.A., D.Sc., M.D., F.R.S., F.R.S.E., F.L.S. (Pres. D, 1894; K, 1901), Professor of Botany in the University of Edinburgh. Inverleith House, Edinburgh.
1883. ‡Balfour, Mrs. I. Bayley. Inverleith House, Edinburgh.
1905. ‡Balfour, Mrs. J. Dawyck, Stobo, N.B.
1905. ‡Balfour, Lewis. 11 Norham-gardens, Oxford.
1905. ‡Balfour, Miss Vera B. Dawyck, Stobo, N.B.
1878. *Ball, Sir Charles Bent, M.D., Regius Professor of Surgery in the University of Dublin. 24 Merrion-square, Dublin.
1866. *BALL, Sir ROBERT STAWELL, LL.D., F.R.S., F.R.A.S. (Pres. A, 1887; Council, 1884–90, 1892–94; Local Sec. 1878), Lowndean Professor of Astronomy and Geometry in the University of Cambridge. The Observatory, Cambridge.
1908. ‡Ball, T. Elrington. 6 Wilton-place, Dublin.
1883. *Ball, W. W. Rouse, M.A. Trinity College, Cambridge.
1905. ‡Ballantine, Rev. T. R. Tirmochree, Bloomfield, Belfast.
1869. ‡Bamber, Henry K., F.C.S. 5 Westminster-chambers, Victoria-street, Westminster, S.W.
1890. ‡Bamford, Professor Harry, M.Sc. 30 Falkland-mansions, Glasgow.
1909. §Bampfield, Mrs. E. 303 Donald-street, Winnipeg, Canada.
1899. §Bampton, Mrs. 42 Marine-parade, Dover.
1905. ‡Banks, Miss Margaret Pierrepont. 10 Regent-terrace, Edinburgh.
1898. ‡Bannerman, W. Bruce, F.S.A. The Lindens, Sydenham-road, Croydon.
1909. ‡Baragar, Charles A. University of Manitoba, Winnipeg, Canada.
1910. §Barber, Miss Mary. 126 Queen's-gate, S.W.
1890. *Barber-Starkey, W. J. S. Aldenham Park, Bridgnorth, Salop.
1861. *Barbour, George. Bolesworth Castle, Tattenhall, Chester.
1860. *Barclay, Robert. High Leigh, Hoddesden, Herts.
1887. *Barclay, Robert. Sedgley New Hall, Prestwich, Manchester.
1902. ‡Barcroft, H., D.L. The Glen, Newry, Co. Down.
1902. ‡Barcroft, Joseph, M.A., B.Sc., F.R.S. King's College, Cambridge.
1904. §Barker, B. T. P., M.A. Fenswood, Long Ashton, Bristol.
1906. *Barker, Geoffrey Palgrave. Henstead Hall, Wrentham, Suffolk.
1899. ‡Barker, John H., M.Inst.C.E. Adderley Park Rolling Mills, Birmingham.
1882. *Barker, Miss J. M. Care of Mrs. Plummer, Prior's-terrace, Tynemouth.
1910. *Barker, Raymond Inglis Palgrave. Henstead Hall, Wrentham, Suffolk.
1898. ‡Barker, W. R. 106 Redland-road, Bristol.

Year of Election.

1909. ‡Barlow, Lieut.-Colonel G. N. H. Care of Messrs. Cox & Co., 16 Charing Cross, S.W.
1889. ‡Barlow, H. W. L., M.A., M.B., F.C.S. The Park Hospital, Hither Green, S.E.
1883. ‡Barlow, J. J. 84 Cambridge-road, Southport.
1885. *BARLOW, WILLIAM, F.R.S., F.G.S. The Red House, Great Stanmore.
1905. *Barnard, Miss Annie T., M.D., B.Sc. 32 Chenies-street-chambers, Gower-street, W.C.
1902. §Barnard, J. E. Park View, Brondesbury Park, N.W.
1881. *Barnard, William, LL.B. 3 New-court, Lincoln's Inn, W.C.
1904. ‡Barnes, Rev. E. W., M.A., Sc.D., F.R.S. Trinity College, Cambridge.
1907. §Barnes, Professor H. T., Sc.D. McGill University, Montreal, Canada.
1909. *Barnett, Miss Edith A. Holm Leas, Worthing.
1881. ‡BARR, ARCHIBALD, D.Sc., M.Inst.C.E., Professor of Civil Engineering in the University, Glasgow.
1902. *Barr, Mark. Gloucester-mansions, Harrington-gardens, S.W.
1904. ‡Barrett, Arthur. 6 Mortimer-road, Cambridge.
1872. *BARRETT, W. F., F.R.S., F.R.S.E., M.R.I.A. 6 De Vesci-terrace, Kingstown, Co. Dublin.
1874. *BARRINGTON, R. M., M.A., LL.B., F.L.S. Fassaroe, Bray, Co. Wicklow.
1874. *Barrington-Ward, Rev. Mark J., M.A., F.L.S., F.R.G.S. The Rectory, Duloe S.O., Cornwall.
1893. *BARROW, GEORGE, F.G.S. 28 Jermyn-street, S.W.
1896. §Barrowman, James. Staneacre, Hamilton, N.B.
1908. ‡Barry, Gerald H. Wiglin Glebe, Carlow, Ireland.
1884. *Barstow, Miss Frances A. Garrow Hill, near York.
1890. *Barstow, J. J. Jackson. The Lodge, Weston-super-Mare.
1890. *Barstow, Mrs. The Lodge, Weston-super-Mare.
1892. ‡Bartholomew, John George, F.R.S.E., F.R.G.S. Newington House, Edinburgh.
1858. *Bartholomew, William Hamond, M.Inst.C.E. Ridgeway House, Cumberland-road, Hyde Park, Leeds.
1909. ‡Bartleet, Arthur M. 138 Hagley-road, Edgbaston, Birmingham.
1909. ‡Bartlett, C. Bank of Hamilton-building, Winnipeg, Canada.
1893. *Barton, Edwin H., D.Sc., F.R.S.E., Professor of Experimental Physics in University College, Nottingham.
1908. ‡Barton, Rev. Walter John, B.A., F.R.G.S. The College, Winchester.
1904. *Bartrum, C. O., B.Sc. 12 Heath-mansions, Heath-street, Hampstead, N.W.
1845. *Bashforth, Rev. Francis, B.D. Woodhall Spa, Lincoln.
1888. *BASSET, A. B., M.A., F.R.S. Fledborough Hall, Holyport, Berkshire.
1891. ‡Bassett, A. B. Cheverell, Llandaff.
1866. *BASSETT, HENRY. 26 Belitha-villas, Barnsbury, N.
1889. ‡BASTABLE, Professor C. F., M.A., F.S.S. (Pres. F, 1894.) 6 Trevelyan-terrace, Rathgar, Co. Dublin.
1871. ‡BASTIAN, H. CHARLTON, M.A., M.D., F.R.S., F.L.S., Emeritus Professor of the Principles and Practice of Medicine in University College, London. Fairfield, Chesham Bois, Bucks.
1883. ‡BATEMAN, Sir A. E., K.C.M.G. Woodhouse, Wimbledon Park, S.W.
1907. *Bateman, Harry. The University, Manchester.
1884. ‡BATESON, WILLIAM, M.A., F.R.S. (Pres. D, 1904.) Manor House, Merton, Surrey.
1881. *BATHER, FRANCIS ARTHUR, M.A., D.Sc., F.R.S., F.G.S. British Museum (Natural History), S.W.

Year of Election.

1906. §Batty, Mrs. Braithwaite. Ye Gabled House, The Parks, Oxford.
1904. ‡Baugh, J. H. Agar. 92 Hatton-garden, E.C.
1909. §Bawlf, Nicholas. Assiniboine-avenue, Winnipeg, Canada.
1905. ‡Baxter, W. Duncan. P.O. Box 103, Cape Town.
1876. *BAYNES, ROBERT E., M.A. Christ Church, Oxford.
1887. *Baynes, Mrs. R. E. 2 Norham-gardens, Oxford.
1883. *Bazley, Gardner S. Hatherop Castle, Fairford, Gloucestershire.
1905. *Bazley, Miss J. M. A. Kilmorie, Ilsham-drive, Torquay, Devon.
Bazley, Sir Thomas Sebastian, Bart., M.A. Kilmorie, Ilsham-drive, Torquay, Devon.
1909. *BEADNELL, H. J. LLEWELLYN, F.G.S. Goldenlands Farm, Dorking, Surrey.
1889. §BEARE, Professor T. HUDSON, B.Sc., F.R.S.E., M.Inst.C.E. The University, Edinburgh.
1905. ‡Beare, Mrs. T. Hudson. 10 Regent-terrace, Edinburgh.
1904. §Beasley, H. C. 25A Prince Alfred-road, Wavertree, Liverpool.
1905. ‡Beattie, Professor J. C., D.Sc., F.R.S.E. South African College, Cape Town.
1910. §Beattie, James M. 12 Caxton-road, Sheffield.
1900. ‡Beaumont, Professor Roberts, M.I.Mech.E. The University, Leeds.
1887. *Beaumont, W. J. The Laboratory, Citadel Hill, Plymouth.
1885. *BEAUMONT, W. W., M.Inst.C.E. Outer Temple, 222 Strand, W.C.
1887. *BECKETT, JOHN HAMPDEN. Corbar Hall, Buxton, Derbyshire.
1904. §Beckit, H. O. Cheney Cottage, Headington, Oxford.
1885. ‡BEDDARD, FRANK E., M.A., F.R.S., F.Z.S., Prosector to the Zoological Society of London, Regent's Park, N.W.
1870. ‡BEDDOE, JOHN, M.D., F.R.S. (Council, 1870–75.) The Chantry, Bradford-on-Avon.
1904. *Bedford, T. G., M.A. 13 Warkworth-street, Cambridge.
1891. ‡Bedlington, Richard. Gadlys House, Aberdare.
1878. ‡BEDSON, P. PHILLIPS, D.Sc., F.C.S. (Local Sec. 1889), Professor of Chemistry in the College of Physical Science, Newcastle-upon-Tyne.
1901. *BEILBY, G. T., LL.D., F.R.S. (Pres. B, 1905.) 11 University-gardens, Glasgow.
1905. ‡Beilby, Hubert. 11 University-gardens, Glasgow.
1891. *Belinfante, L. L., M.Sc., Assist. Sec. G.S. Burlington House, W.
1909. ‡BELL, C. N. (Local Sec. 1909.) 121 Carlton-street, Winnipeg, Canada.
1894. ‡BELL, F. JEFFREY, M.A., F.Z.S. British Museum, S.W.
1900. *Bell, Henry Wilkinson. Beech Cottage, Rawdon, near Leeds.
1870. *BELL, J. CARTER, A.R.S.M. The Cliff, Higher Broughton, Manchester.
1883. *Bell, John Henry. 102 Leyland-road, Southport.
1905. ‡Bell, W. H. S. P.O. Box 4284, Johannesburg.
1888. *Bell, Walter George, M.A. Trinity Hall, Cambridge.
1908. *Bellamy, Frank Arthur, M.A., F.R.A.S. University Observatory, Oxford.
1904. ‡Bellars, A. E. Magdalene College, Cambridge.
1905. ‡Bender, Rev. A. P., M.A. Synagogue House, Cape Town.
1883. *Bennett, Laurence Henry. The Elms, Paignton, South Devon.
1901. ‡Bennett, Professor Peter. 207 Bath-street, Glasgow.
1909. *Bennett, R. B., K.C. Calgary, Alberta, Canada.
1905. §Benson, Arthur H., M.A., F.R.C.S.I. 42 Fitzwilliam-square, Dublin.
1905. §Benson, Mrs. A. H. 42 Fitzwilliam-square, Dublin.
1909. ‡Benson, Miss C. C. Terralta, Port Hope, Ontario, Canada.
1903. §Benson, D. E. Queenwood, 12 Irton-road, Southport.

Year of Election.

1901. *Benson, Miss Margaret J., D.Sc. Royal Holloway College, Egham.
1887. *Benson, Mrs. W. J. 5 Wellington-court, Knightsbridge, S.W.
1898. *Bent, Mrs. Theodore. 13 Great Cumberland-place, W.
1904. ‡Bentley, B. H. The University, Sheffield.
1905. *Bentley, Wilfred. Rein Wood, Huddersfield.
1908. §Benton, Mrs. Evelyn M. Kingswear, Hale, Altrincham, Cheshire.
1896. *Bergin, William, M.A., Professor of Natural Philosophy in University College, Cork.
1894. §Berkeley, The Earl of, F.R.S., F.C.S. (Council, 1909-10.) Foxcombe, Boarshill, near Abingdon.
1905. *Bernacchi, L. C., F.R.G.S. Pound Farm, Upper Long Ditton, Surrey.
1906. *Bernays, Albert Evan. 3 Priory-road, Kew, Surrey.
1898. §Berridge, Miss C. E. 107 Albert Palace-mansions, Battersea Park, S.W.
1894. §Berridge, Douglas, M.A., F.C.S. The College, Malvern.
1908. *Berridge, Miss Emily M. Dunton Lodge, The Knoll, Beckenham.
1908. *Berry, Arthur J. 5 University-gardens, Glasgow.
1904. §Berry, R. A., Ph.D., West of Scotland Agricultural College, 6 Blythswood-square, Glasgow.
1905. ‡Bertrand, Captain Alfred. Champel, Geneva.
1862. ‡Besant, William Henry, M.A., Sc.D., F.R.S. St. John's College, Cambridge.
1880. *Bevan, Rev. James Oliver, M.A., F.S.A., F.G.S. Chillenden Rectory, Canterbury.
1904. *Bevan, P. V., M.A. Hillside, Egham.
1906. ‡Bevan-Lewis, W., M.D. West Riding Asylum, Wakefield.
1884. *Beverley, Michael, M.D. 54 Prince of Wales-road, Norwich.
1903. ‡Bickerdike, C. F. 1 Boverney-road, Honor Oak Park, S.E.
1888. *Bidder, George Parker. Savile Club, Piccadilly, W.
1910. ‡Biddlecombe, A. 50 Grainger-street, Newcastle-on-Tyne.
1904. §Bigg-Wither, Colonel A. C., F.R.A.S. Tilthams, Godalming, Surrey.
1882. ‡Biggs, C. H. W., F.C.S. Glebe Lodge, Champion-hill, S.E.
1911. §Biles, J. H., LL.D., D.Sc., Professor of Naval Architecture in the University of Glasgow. 10 University-gardens, Glasgow.
1898. ‡Billington, Charles. Heimath, Longport, Staffordshire.
1901. *Bilsland, Sir William, Bart., J.P. 28 Park-circus, Glasgow.
1908. *Bilton, Edward Barnard. Graylands, Wimbledon Common, S.W.
1887. *Bindloss, James B. Elm Bank, Buxton.
1909. §Bingham, Alexander R. 16 Kingsmead-road South, Birkenhead.
1884. *Bingham, Colonel Sir John E., Bart. West Lea, Ranmoor, Sheffield.
1881. ‡Binnie, Sir Alexander R., M.Inst.C.E., F.G.S. (Pres. G, 1900.) 77 Ladbroke-grove, W.
1910. *Birchenough, C., M.A. 8 Severn-road, Sheffield.
1887. *Birley, H. K. Penrhyn, Irlams o' th' Height, Manchester.
1904. ‡Bishop, A. W. Edwinstowe, Chaucer-road, Cambridge.
1906. §Bishop, J. L. Customs and Excise Office, York.
1894. ‡Bisset, James, F.R.S.E. 9 Greenhill-park, Edinburgh.
1910. §Bisset, John. Thornhill, Insch, Aberdeenshire.
1886. *Bixby, General W. H. 508 Colorado-building, Washington, U.S.A.
1909. ‡Black, W. J., Principal of Manitoba Agricultural College, Winnipeg, Canada.
1901. §Black, W. P. M. 136 Wellington-street, Glasgow.
1903. *Blackman, F.F., M.A., D.Sc., F.R.S. (Pres. K, 1908.) St. John's College, Cambridge.

Year of Election.

1908. §Blackman, Professor V. H., M.A., Sc.D. The University, Leeds.
1909. ‡Blaikie, Leonard, M.A. Civil Service Commission, Burlington-gardens, W.
1910. §Blair, R., M.A. London County Council, Spring-gardens, S.W.
1902. ‡Blake, Robert F., F.I.C. Queen's College, Belfast.
1900. *Blamires, Joseph. Bradley Lodge, Huddersfield.
1905. ‡Blamires, Mrs. Bradley Lodge, Huddersfield.
1904. ‡Blanc, Dr. Gian Alberto. Istituto Fisico, Rome.
1884. *Blandy, William Charles, M.A. 1 Friar-street, Reading.
1887. *Bles, Edward J., M.A., D.Sc. The Mill House, Iffley, Oxford.
1884. *Blish, William G. Niles, Michigan, U.S.A.
1902. ‡Blount, Bertram, F.I.C. 76 & 78 York-street, Westminster, S.W.
1888. ‡Bloxsom, Martin, B.A., M.Inst.C.E. Hazelwood, Crumpsall Green, Manchester.
1909. §Blumfeld, Joseph, M.D. 7 Cavendish-place, W.
Blyth, B. Hall. 135 George-street, Edinburgh.
1887. *Boddington, Henry. Pownall Hall, Wilmslow, Manchester.
1900. ‡BODINGTON, Sir NATHAN, Litt.D. The University, Leeds.
1908. §BOEDDICKER, OTTO, Ph.D. Birr Castle Observatory, Birr, Ireland.
1887. *Boissevain, Gideon Maria. 4 Tesselschade-straat, Amsterdam.
1898. §BOLTON, H., F.R.S.E. The Museum, Queen's-road, Bristol.
1894. §BOLTON, JOHN. 15 Cranley-gardens, Muswell Hill, N.
1898. *BONAR, JAMES, M.A., LL.D. (Pres. F, 1898; Council, 1899–1905.) The Mint, Ottawa, Canada.
1909. ‡Bonar, Thomson, M.D. 114 Via Babuino, Piazza di Spagna, Rome.
1909. ‡Bond, J. H. R., M.B. 167 Donald-street, Winnipeg, Canada.
1908. ‡BONE, Professor W. A., D.Sc., F.R.S. The University, Leeds.
1871. *BONNEY, Rev. THOMAS GEORGE, Sc.D., LL.D., F.R.S., F.S.A., F.G.S. (PRESIDENT; SECRETARY, 1881–85; Pres. C, 1886.) 9 Scroope-terrace, Cambridge.
1888. ‡Boon, William. Coventry.
1893. ‡Boot, Sir Jesse. Carlyle House, 18 Burns-street, Nottingham.
1890. *BOOTH, Right Hon. CHARLES, D.Sc., F.R.S., F.S.S. 28 Campden House Court, Kensington, W.
1883. ‡Booth, James. Hazelhurst, Turton.
1910. §Booth, John. 25 Rathdown-street, Carlton, Melbourne, Australia.
1908. §Booth, Robert, J.P. Bartra Hall, Dalkey, Co. Dublin.
1883. ‡Boothroyd, Benjamin. Weston-super-Mare.
1901. *Boothroyd, Herbert E., M.A., B.Sc. Sidney Sussex College, Cambridge.
1882. §BORNS, HENRY, Ph.D., F.C.S. 5 Sutton Court-road, Chiswick, W.
1901. ‡Borradaile, L. A., M.A. Selwyn College, Cambridge.
1876. *BOSANQUET, R. H. M., M.A., F.R.S., F.R.A.S. Castillo Zamora, Realejo-Alto, Teneriffe.
1903. §Bosanquet, Robert C., M.A., Professor of Classical Archæology in the University of Liverpool. Institute of Archæology, 40 Bedford-street, Liverpool.
1896. ‡Bose, Professor J. C., C.I.E., M.A., D.Sc. Calcutta, India.
1881. §BOTHAMLEY, CHARLES H., M.Sc., F.I.C., F.C.S., Education Secretary, Somerset County Council, Weston-super-Mare.
1871. *BOTTOMLEY, JAMES THOMSON, M.A., LL.D., D.Sc., F.R.S., F.R.S.E., F.C.S. 13 University-gardens, Glasgow.
1884. *Bottomley, Mrs. 13 University-gardens, Glasgow.
1892. *Bottomley, W. B., B.A., Professor of Botany in King's College, W.C.
1909. §Boulenger, C. L. 8 Courtfield-road, S.W.
1905. §BOULENGER, G. A., F.R.S. (Pres. D, 1905.) 8 Courtfield-road, S.W.

Year of Election.

1905. §Boulenger, Mrs. 8 Courtfield-road, S.W.
1903. §Boulton, W. S., B.Sc., F.G.S., Professor of Geology in University College, Cardiff. 26 Arches-road, Penarth.
1883. ‡Bourne, A. G., C.I.E., D.Sc., F.R.S., F.L.S. Adyar, Madras.
1893. *Bourne, G. C., M.A., D.Sc., F.R.S., F.L.S. (Pres. D, 1910; Council, 1903-09; Local Sec. 1894), Linacre Professor of Comparative Anatomy in the University of Oxford. Savile House, Mansfield-road, Oxford.
1904. **Bousfield, E. G. P. Clarendon Lodge, Blyth Bridge, Stoke-on-Trent.*
1884. ‡Bovey, Henry T., M.A., LL.D., F.R.S., M.Inst.C.E. 16 Hans-road, S.W.
1881. *Bower, F. O., D.Sc., F.R.S., F.R.S.E., F.L.S. (Pres. K, 1898; Council, 1900-06), Regius Professor of Botany in the University of Glasgow.
1898. *Bowker, Arthur Frank, F.R.G.S., F.G.S. Whitehill, Wrotham, Kent.
1856. *Bowlby, Miss F. E. 4 South Bailey, Durham.
1908. §Bowles, E. Augustus, M.A., F.L.S. Myddelton House, Waltham Cross, Herts.
1898. §Bowley, A. L., M.A. (Pres. F, 1906; Council, 1906- .) Northcourt-avenue, Reading.
1880. ‡Bowly, Christopher. Cirencester.
1887. ‡Bowly, Mrs. Christopher. Cirencester.
1899. *Bowman, Herbert Lister, M.A., D.Sc., F.G.S., Professor of Mineralogy in the University of Oxford. Magdalen College, Oxford.
1899. *Bowman, John Herbert. Greenham Common, Newbury.
1887. §Box, Alfred Marshall. Woodlands, Magrath Avenue, Cambridge.
1895. *Boyce, Sir Rubert, M.B., F.R.S., Professor of Pathology in the University of Liverpool.
1901. ‡Boyd, David T. Rhinsdale, Ballieston, Lanark.
1892. ‡Boys, Charles Vernon, F.R.S. (Pres. A, 1903; Council, 1893-99, 1905-08.) 66 Victoria-street, S.W.
1872. *Brabrook, Sir Edward, C.B., F.S.A. (Pres. H, 1898; Pres. F, 1903; Council, 1903-10.) 178 Bedford-hill, Balham, S.W.
1869. *Braby, Frederick, F.G.S., F.C.S. Bushey Lodge, Teddington, Middlesex.
1894. *Braby, Ivon. Helena, Alan-road, Wimbledon, S.W.
1905. ‡Bradford, Wager. P.O. Box 5, Johannesburg.
1893. §Bradley, F. L. Ingleside, Malvern Wells.
1904. *Bradley, Gustav. Council Offices, Goole.
1899. *Bradley, J. W., Assoc.M.Inst.C.E. Westminster City Hall, Charing Cross-road, W.C.
1903. *Bradley, O. Charnock, D.Sc., M.D., F.R.S.E. Royal Veterinary College, Edinburgh.
1892. ‡Bradshaw, W. Carisbrooke House, The Park, Nottingham.
1863. ‡Brady, George S., M.D., LL.D., F.R.S. Park Hurst, Endcliffe, Sheffield.
1880. *Brady, Rev. Nicholas, M.A. Rainham Hall, Rainham, S.O., Essex.
1905. §Brakhan, A. Clare Bank, The Common, Sevenoaks.
1906. §Branfield, Wilfrid. 4 Victoria-villas, Upperthorpe, Sheffield.
1885. *Bratby, William, J.P. Alton Lodge, Lancaster Park, Harrogate.
1905 ‡Brausewetter, Miss. Roedean School, near Brighton.
1909. §Bremner, Alexander. 38 New Broad-street, E.C.
1905. ‡Bremner, R. S. Westminster-chambers, Dale-street, Liverpool.
1905. ‡Bremner, Stanley. Westminster-chambers, Dale-street, Liverpool.

Year of Election.

1902. *Brereton, Cloudesley. Briningham House, Briningham, S.O., Norfolk.
1882. **Bretherton, C. E. 26 Palace-mansions, Addison Bridge, W.*
1909. *Breton, Miss A. C. 15 Camden-crescent, Bath.
1905. §Brewis, E. 27 Winchelsea-road, Tottenham, N.
1908. §Brickwood, Sir John. Branksmere, Southsea.
1907. *Bridge, Henry Hamilton. North Lodge, Battle, Sussex.
1870. *Brigg, Sir John, M.P. Kildwick Hall, Keighley, Yorkshire.
1904. *Briggs, William, M.A., LL.D., F.R.A.S. Burlington House, Cambridge.
1909. §Briggs, Mrs. Owlbrigg, Cambridge.
1905. ‡Brill, J., Litt.D. Grey College, Bloemfontein, South Africa.
1908. ‡Brindley, H. H. 4 Devana-terrace, Cambridge.
1893. ‡Briscoe, Albert E., B.Sc., A.R.C.Sc. The Hoppet, Little Baddow, Chelmsford.
1904. ‡Briscoe, J. J. Bourn Hall, Bourn, Cambridge.
1905. §Briscoe, Miss. Bourn Hall, Bourn, Cambridge.
1898. ‡Bristol, The Right Rev. G. F. Browne, D.D., Lord Bishop of. 17 The Avenue, Clifton, Bristol.
1879. *Brittain, W. H., J.P., F.R.G.S. Storth Oaks, Sheffield.
1905. *Broadwood, Brigadier-General R. G. The Deodars, Bloemfontein, South Africa.
1905. §Brock, Dr. B. G. P.O. Box 216, Germiston, Transvaal.
1907. ‡Brockington, W. A., M.A. Leicestershire County Council, 38 Bowling Green-street, Leicester.
1896. *Brocklehurst, S. Olinda, Sefton Park, Liverpool.
1901. ‡Brodie, T. G., M.D., F.R.S., Professor of Physiology in the University of Toronto. The University, Toronto, Canada.
1883. *Brodie-Hall, Miss W. L. 5 Devonshire-place, Eastbourne.
1905. ‡Brodigan, C. B. Brakpan Mines, Johannesburg.
1903. ‡Brodrick, Harold, M.A., F.G.S. (Local Sec. 1903.) 7 Aughton-road, Birkdale, Southport.
1904. ‡Bromwich, T. J. I'A., M.A., F.R.S., Professor of Mathematics in Queen's College, Galway.
1906. ‡Brook, Stanley. 18 St. George's-place, York.
1905. **Brooke, Geoffrey. Christ Church Vicarage, Mirfield, S.O., Yorkshire.*
1906. *Brooks, F. T. 102 Mawson-road, Cambridge.
1883. *Brotherton, E. A., M.P. 16 St. James's-place, S.W.
1883. *Brough, Mrs. Charles S. 12 Salisbury-road, Southsea.
1886. ‡Brough, Joseph, LL.D., Professor of Logic and Philosophy in University College, Aberystwyth.
1905. ‡Brown, A. R. Trinity College, Cambridge.
1863. *Brown, Alexander Crum, M.D., LL.D., F.R.S., F.R.S.E., V.P.C.S. (Pres. B, 1874; Local Sec. 1871.) 8 Belgrave-crescent, Edinburgh.
1883. ‡Brown, Mrs. Ellen F. Campbell. 27 Abercromby-square, Liverpool.
1905. §Brown, Professor Ernest William, M.A., D.Sc., F.R.S. Yale University, New Haven, Conn., U.S.A.
1903. ‡Brown, F. W. 6 Rawlinson-road, Southport.
1870. §Brown, Horace T., LL.D., F.R.S., F.G.S. (Pres. B, 1899; Council, 1904– .) 52 Nevern-square, S.W.
1905. ‡Brown, J. Ellis. Durban, Natal.
1876. §Brown, John, F.R.S. (Local Sec. 1902.) Longhurst, Dunmurry, Belfast.
1881. *Brown, John, M.D. 2 Glebe-terrace, Rondebosch, Cape Colony.
1895. *Brown, John Charles. 39 Burlington-road, Sherwood, Nottingham.

Year of Election

1905. ‡Brown, John S. Longhurst, Dunmurry, Belfast.
1905. ‡Brown, L. Clifford. Beyer's Kloof, Klapmuts, Cape Colony.
1882. *Brown, Mrs. Mary. 2 Glebe-terrace, Rondebosch, Cape Colony.
1898. §Brown, Nicol, F.G.S. 4 The Grove, Highgate, N.
1905. ‡Brown, R. C. Strathyre, Troyville, Transvaal.
1901. ‡Brown, Professor R. N. Rudmose, D.Sc. The University, Sheffield.
1908. §Brown, Sidney G. 52 Kensington Park-road, W.
1905. §Brown, Mrs. Sidney G. 52 Kensington Park-road, W.
1910. *Brown, Sidney J. R. 52 Kensington Park-road, W.
1884. ‡Brown, W. G. University of Missouri, Columbia, Missouri, U.S.A.
1908. ‡Brown, William, B.Sc. 48 Dartmouth-square, Dublin.
1906. ‡Browne, Charles E., B.Sc. Christ's Hospital, West Horsham.
1900. *Browne, Frank Balfour, M.A., F.R.S.E., F.Z.S. Claremont, Holywood, Co. Down.
1908. ‡Browne, Rev. Henry, M.A. University College, Dublin.
1895. *Browne, H. T. Doughty. 6 Kensington House, Kensington-court, W.
1879. ‡BROWNE, Sir J. CRICHTON, M.D., LL.D., F.R.S., F.R.S.E. 61 Carlisle-place-mansions, Victoria-street, S.W.
1905. *Browne, James Stark, F.R.A.S. The Red House, Mount-avenue, Ealing, W.
1883. ‡Browning, Oscar, M.A. King's College, Cambridge.
1905. §BRUCE, Colonel Sir DAVID, C.B., M.B., F.R.S. (Pres. I, 1905.) Royal Army Medical College, Grosvenor-road, S.W.
1905. ‡Bruce, Lady. 3P Artillery-mansions, Victoria-street, S.W.
1893. ‡Bruce, William S., LL.D., F.R.S.E. Antarctica, Joppa, Edinburgh.
1902. ‡Bruce-Kingsmill, Major J., F.C.S. 4, St. Ann's-square, Manchester.
1900. *Brumm, Charles. Lismara, Grosvenor-road, Birkdale, Southport.
1896. *Brunner, Right Hon. Sir J. T., Bart., M.P. Druid's Cross, Wavertree, Liverpool.
1868. ‡BRUNTON, Sir T. LAUDER, Bart., M.D., D.Sc., F.R.S. (Council, 1908– .) 10 Stratford-place, Cavendish-square, W.
1897. *Brush, Charles F. Cleveland, Ohio, U.S.A.
1886. *BRYAN, G. H., D.Sc., F.R.S., Professor of Mathematics in University College, Bangor.
1894. ‡Bryan, Mrs. R. P. Plas Gwyn, Bangor.
1910. §Bryant, Miss Ella M. The Hayes, Corbridge-on-Tyne.
1884. *BRYCE, Rev. Professor GEORGE, D.D., LL.D. Kilmadock, Winnipeg, Canada.
1909. ‡Bryce, Thomas H., M.D., Professor of Anatomy in the University of Glasgow. 2 The College, Glasgow.
1902. *Bubb, Miss E. Maude. Ullenwood, near Cheltenham.
1890. §Bubb, Henry. Ullenwood, near Cheltenham.
1902. *Buchanan, Miss Florence, D.Sc. University Museum, Oxford.
1905. §Buchanan, Right Hon. Sir John. Clareinch, Claremont, Cape Town.
1881. *Buchanan, John H., M.D. Sowerby, Thirsk.
1871. ‡BUCHANAN, JOHN YOUNG, M.A., F.R.S., F.R.S.E., F.R.G.S., F.C.S. Christ's College, Cambridge.
1909. ‡Buchanan, W. W. P.O. Box 1658, Winnipeg, Canada.
1884. *Buckmaster, Charles Alexander, M.A., F.C.S. 16 Heathfield-road, Mill Hill Park, W.
1904. ‡Buckwell, J. C. North Gate House, Pavilion, Brighton.
1893. §BULLEID, ARTHUR, F.S.A. Dymboro, Midsomer Norton, Bath.
1903. *Bullen, Rev. R. Ashington, F.L.S., F.G.S. Hilden Manor, Tonbridge, Kent.
1909. ‡BULYEA, The Hon. G. H. V. Edmonton, Alberta, Canada.

Year of Election.

1905. ‡Burbury, Mrs. A. A. 17 Upper Phillimore-gardens, W.
1905. ‡Burbury, Miss A. D. 17 Upper Phillimore-gardens, W.
1886. §BURBURY, S. H., M.A., F.R.S. 1 New-square, Lincoln's Inn, W.C.
1907. ‡Burch, George J., M.A., D.Sc.. F.R.S. 28 Norham-road, Oxford.
1881. ‡Burdett-Coutts, William Lehmann, M.P. 1 Stratton-street, Piccadilly, W.
1905. ‡Burdon, E. R., M.A. Ikenhilde, Royston, Herts.
1894. ‡BURKE, JOHN B. B. Trinity College, Cambridge.
1884. *Burland, Lieut.-Colonel Jeffrey H. 342 Sherbrooke-street West, Montreal, Canada.
1905. ‡Burmeister, H. A. P. 78 Hout-street, Cape Town.
1904. ‡Burn, R. H. 21 Stanley-crescent, Notting-hill, W.
1885. *Burnett, W. Kendall, M.A. Migvie House, North Silver-street, Aberdeen.
1909. ‡Burns, F. D. 203 Morley-avenue, Winnipeg, Canada.
1908. ‡Burnside, W. Snow, D.Sc., Professor of Mathematics in the University of Dublin. 35 Raglan-road, Dublin.
1905. ‡Burroughes, James S., F.R.G.S. The Homestead, Seaford, Sussex.
1909. ‡Burrows, Theodore Arthur. 187 Kennedy-street, Winnipeg, Canada.
1910. §Burt, Cyril. The University, Liverpool.
1909. ‡Burton, E. F. 129 Howland-avenue, Toronto, Canada.
1866. *BURTON, FREDERICK M., F.L.S., F.G.S. Highfield, Gainsborough.
1892. ‡Burton-Brown, Colonel Alexander, R.A., F.R.A.S., F.G.S. 11 Union-crescent, Margate.
1904. ‡Burtt, Arthur H., D.Sc. 4 South View, Holgate, York.
1906. §Burtt, Philip. Swarthmore, St. George's-place, York.
1909. ‡Burwash, E. M., M.A. New Westminster, British Columbia, Canada.
1887. *Bury, Henry. Mayfield House, Farnham, Surrey.
1899. §Bush, Anthony. 43 Portland-road, Nottingham.
1895. ‡Bushe, Colonel C. K., F.G.S. 19 Cromwell-road, S.W.
1906. §Bushell, H. A. Melton House, Holgate Hill, York.
1908. *Bushell, W. F. The Hermitage, Harrow.
1910. §Butcher, Miss. 25 Earl's Court-square, S.W.
1884. *Butcher, William Deane, M.R.C.S.Eng. Holyrood, 5 Cleveland-road, Ealing, W.
1884. *Butterworth, W. Verona, 9 Knowles-road, St. Anne's-on-the-Sea, Lancashire.
1887. *Buxton, J. H. Clumber Cottage, Montague-road, Felixstowe.
1899. ‡Byles, Arthur R. 'Bradford Observer,' Bradford, Yorkshire.

1908. ‡Cadic, Edouard, D.Litt. Mon Caprice, Pembroke Park, Dublin.
1861. *Caird, James Key, LL.D. 8 Roseangle, Dundee.
1905. ‡Calderwood, J. M. P.O. Box 2295, Johannesburg.
1901. ‡Caldwell, Hugh. Blackwood, Newport, Monmouthshire.
1907. ‡Caldwell, K. S. St. Bartholomew's Hospital, S.E.
1908. §Caldwell, Colonel R. T., M.A., LL.M., LL.D., Master of Corpus Christi College, Cambridge.
1897. ‡CALLENDAR, HUGH L., M.A., LL.D., F.R.S. (Council, 1900–06), Professor of Physics in the Imperial College of Science, S.W.
1857. ‡CAMERON, Sir CHARLES A., C.B., M.D. 51 Pembroke-road, Dublin.
1909. ‡Cameron, D. C. 65 Roslyn-road, Winnipeg, Canada.
1896. §Cameron, Irving H. 307 Sherbourne-street, Toronto, Canada

Year of Election.

1909. ‡Cameron, Hon. Mr. Justice J. D. Judges' Chambers, Winnipeg, Canada.
1901. ‡Campbell, Archibald. Park Lodge, Albert-drive, Pollokshields, Glasgow.
1897. ‡Campbell, Colonel J. C. L. Achalader, Blairgowrie, N.B.
1909. *Campbell, R. J. Rideau Hall, 85 Kennedy-street, Winnipeg, Canada.
1909. ‡Campbell, Mrs. R. J. Rideau Hall, 85 Kennedy-street, Winnipeg, Canada.
1902. ‡Campbell, Robert. 21 Great Victoria-street, Belfast.
1890. ‡CANNAN, Professor EDWIN, M.A., LL.D., F.S.S. (Pres. F, 1902.) 11 Chadlington-road, Oxford.
1905. ‡Cannan, Gilbert. King's College, Cambridge.
1897. §Cannon, Herbert. Alconbury, Bexley Heath, Kent.
1905. ‡Cape Town, The Archbishop of. Bishop's-court, Claremont, Cape Colony.
1904. ‡Capell, Rev. G. M. Passenham Rectory, Stony Stratford.
1905. *Caporn, Dr. A. W. Roeland-street Baths, Cape Town.
1894. ‡CAPPER, D. S., M.A., Professor of Mechanical Engineering in King's College, W.C.
1896. **Carden, H. Vandeleur. Fassaroe, Walmer.*
1902. ‡Carpenter, G. H., B.Sc., Professor of Zoology in the Royal College of Science, Dublin.
1906. *Carpenter, H. C. H. 11 Oak-road, Withington, Manchester.
1905. §Carpmael, Edward, F.R.A.S., M.Inst.C.E. 24 Southampton-buildings, Chancery-lane, W.C.
1910. §Carr, Henry F. Broadparks, Pinhoe, near Exeter.
1893. ‡CARR, J. WESLEY, M.A., F.L.S., F.G.S., Professor of Biology in University College, Nottingham.
1906. *Carr, Richard E., British Vice-Consul, Cordoba, Spain.
1889. ‡Carr-Ellison, John Ralph. Hedgeley, Alnwick.
1905. ‡Carrick, Dr. P.O. Box 646, Johannesburg.
1867. ‡CARRUTHERS, WILLIAM, F.R.S., F.L.S., F.G.S. (Pres. D, 1886.) 14 Vermont-road, Norwood, S.E.
1886. ‡CARSLAKE, J. BARHAM. (Local Sec. 1886.) 30 Westfield-road, Birmingham.
1899. ‡Carslaw, H. S., D.Sc., Professor of Mathematics in the University of Sydney, N.S.W.
1900. *Carter, W. Lower, M.A., F.G.S. 11 Twyford-avenue, Acton Hill, W.
1896. ‡Cartwright, Miss Edith G. 21 York Street-chambers, Bryanston-square, W.
1878. *Cartwright, Ernest H., M.A., M.D. Myskyns, Ticehurst, Sussex.
1870. §Cartwright, Joshua, M.Inst.C.E., F.S.I. 21 Parsons-lane, Bury, Lancashire.
1862. ‡Carulla, F. J. R. 84 Rosehill-street, Derby.
1894. ‡Carus, Dr. Paul. La Salle, Illinois, U.S.A.
1901. ‡Carver, Thomas A. B., D.Sc., Assoc.M.Inst.C.E. 118 Napiershall-street, Glasgow.
1897. *Case, Willard E. Auburn, New York, U.S.A.
1873. *Cash, William, F.G.S. 26 Mayfield-terrace South, Halifax.
1908. *Cave, Charles J. P., M.A. Ditcham Park, Petersfield.
1886. *Cave-Moyle, Mrs. Isabella. St. Paul's Vicarage, Cheltenham.
Cayley, Digby. Brompton, near Scarborough.
1910. §Chadburn, A. W. Brincliffe Rise, Sheffield.
1905. *Challenor, Bromley, M.A. The Firs, Abingdon.
1905. *Challenor, Miss E. M. The Firs, Abingdon.

Year of Election.

1910. §Chalmers, St. Stephen D. 25 Cornwall-road, Stroud Green, N.
1905. ‡Chamberlain, Miss H. H. Ingleneuk, Upper St. John's-road, Sea Point, Cape Colony.
1901. §Chamen, W. A. South Wales Electrical Power Distribution Company, Royal-chambers, Queen-street, Cardiff.
1905. ‡Champion, G. A. Haraldene, Chelmsford-road, Durban, Natal.
1881. *Champney, John E. 27 Hans-place, S.W.
1908. ‡Chance, Sir Arthur, M.D. 90 Merrion-square, Dublin.
1907. *Chapman, Alfred Chaston, F.I.C. 8 Duke-street, Aldgate, E.C.
1902. §Chapman, D. L. Jesus College, Oxford.
1910. §Chapman, J. E. Kinross.
1899. §CHAPMAN, Professor SYDNEY JOHN, M.A., M.Com. (Pres. F, 1909.) Burnage Lodge, Levenshulme, Manchester.
1910. §Chappell, Cyril. 73 Neill-road, Sheffield.
1905. ‡Chassigneux, E. 12 Tavistock-road, Westbourne-park, W.
1904. *Chattaway, F. D., M.A., D.Sc., Ph.D., F.R.S. 103 Woodstock-road, Oxford.
1886. *CHATTOCK, A. P., M.A., Professor of Experimental Physics in University College, Bristol. Heathfield Cottage, Crowcombe, near Taunton.
1904. *Chaundy, Theodore William, B.A. 49 Broad-street, Oxford.
1900. §Cheesman, W. Norwood, J.P., F.L.S. The Crescent, Selby.
1874. *Chermside, Lieut.-General Sir Herbert, R.E., G.C.M.G., C.B. Newstead Abbey, Nottingham.
1908. ‡Cherry, Right Hon. R. R. 92 St. Stephen's Green, Dublin.
1910. §Chesney, Miss Lilian M., M.B. 381 Glossop-road, Sheffield.
1879. *Chesterman, W. Belmayne, Sheffield.
1908. ‡Chill, Edwin, M.D. Westleigh, Mattock-road, Ealing, W.
1883. ‡Chinery, Edward F. Monmouth House, Lymington.
1884. ‡Chipman, W. W. L. 957 Dorchester-street, Montreal, Canada.
1894. ‡CHISHOLM, G. G., M.A., B.Sc., F.R.G.S. (Pres. E, 1907.) 12 Hallhead-road, Edinburgh.
1899. §Chitty, Edward. Sonnenberg, Castle-avenue, Dover.
1899. ‡Chitty, Mrs. Edward. Sonnenberg, Castle-avenue, Dover.
1904. ‡Chivers, John, J.P. Histon, Cambridgeshire.
1882. ‡Chorley, George. Midhurst, Sussex.
1909. ‡Chow, H. H., M.D. 263 Broadway, Winnipeg, Canada.
1893. *CHREE, CHARLES, D.Sc., F.R.S. Kew Observatory, Richmond, Surrey.
1900. *Christie, R. J. Duke-street, Toronto, Canada.
1875. *Christopher, George, F.C.S. May Villa, Lucien-road, Tooting Common, S.W.
1876. *CHRYSTAL, GEORGE, M.A., LL.D., F.R.S.E. (Pres. A, 1885), Professor of Mathematics in the University of Edinburgh. 5 Belgrave-crescent, Edinburgh.
1905. ‡Chudleigh, C. P.O. Box 743, Johannesburg.
1870. §CHURCH, Sir A. H., K.C.V.O., M.A., F.R.S., F.S.A., Professor of Chemistry in the Royal Academy of Arts. Shelsley, Ennerdale-road, Kew.
1903. ‡Clapham, J. H., M.A. King's College, Cambridge.
1901. §Clark, Professor Archibald B., M.A. University of Manitoba, Winnipeg, Canada.
1905. *Clark, Cumberland, F.R.G.S. 29 Chepstow-villas, Bayswater, W.
1907. *Clark, Mrs. Cumberland. 29 Chepstow-villas, Bayswater, W.
1877. *Clark, F. J., J.P., F.L.S. Netherleigh, Street, Somerset.
1902. ‡Clark, G. M. South African Museum, Cape Town.
1908. §Clark, James, B.Sc. Newtown School, Waterford, Ireland.

Year of Election.

1881. *Clark, J. Edmund, B.A., B.Sc. Asgarth, Riddlesdown-road, Purley, Surrey.
1909. §Clark, J. M., M.A., K.C. 16 King-street West, Toronto, Canada.
1908. §Clark, John R. W. Brothock Bank House, Arbroath, Scotland.
1901. *Clark, Robert M., B.Sc., F.L.S. 27 Albyn-place, Aberdeen.
1907. *Clarke, E. Russell. 11 King's Bench-walk, Temple, E.C.
1902. *Clarke, Miss Lilian J., B.Sc., F.L.S. Chartfield Cottage, Brasted Chart, Kent.
1905. ‡Clarke, Rev. W. E. C., M.A. P.O. Box 1144, Pretoria.
1889. *Clayden, A. W., M.A., F.G.S. 5 The Crescent, Mount Radford, Exeter.
1908. *Clayton, Miss Edith M. Brackendene, Horsell, Surrey.
1909. §Cleeves, Frederick, F.Z.S. 23 Lime-street, E.C.
1909. ‡Cleeves, W. B. Public Works Department, Government-buildings, Pretoria.
1861. ‡Cleland, John, M.D., D.Sc., F.R.S. Drumclog, Crewkerne, Somerset.
1905. §Cleland, Mrs. Drumclog, Crewkerne, Somerset.
1905. §Cleland, J. R. Drumclog, Crewkerne, Somerset.
1902. ‡Clements, Olaf P. Tana, St. Bernard's-road, Olton, Warwick.
1904. §Clerk, Dugald, F.R.S., M.Inst.C.E. (Pres. G, 1908.) 18 Southampton-buildings, W.C.
1909. §Cleve, Miss E. K. P. 74 Kensington Gardens-square, W.
1861. *Clifton, R. Bellamy, M.A., F.R.S., F.R.A.S., Professor of Experimental Philosophy in the University of Oxford. 3 Bardwell-road, Banbury-road, Oxford.
1906. §Close, Colonel C. F., R.E., C.M.G., F.R.G.S. (Council, 1908– .) Army and Navy Club, Pall Mall, S.W.
1883. *Clowes, Frank, D.Sc., F.C.S. (Local Sec. 1893.) The Grange, College-road, Dulwich, S.E.
1891. *Coates, Henry, F.R.S.E. Balure, Perth.
1903. *Coates, W. M. Queens' College, Cambridge.
1884. §Cobb, John. Fitzharris, Abingdon.
1908. *Cochrane, Miss Constance. The Downs, St. Neots.
1864. *Cochrane, James Henry. Burston House, Pittville, Cheltenham.
1908. ‡Cochrane, Robert, I.S.O., LL.D., F.S.A. 17 Highfield-road, Dublin.
1901. ‡Cockburn, Sir John, K.C.M.G., M.D. 10 Gatestone-road, Upper Norwood, S.E.
1883. ‡Cockshott, J. J. 24 Queen's-road, Southport.
1861. *Coe, Rev. Charles C., F.R.G.S. Whinsbridge, Grosvenor-road, Bournemouth.
1908. ‡Coffey, Denis J., M.B. 2 Arkendale-road, Glenageary, Co. Dublin.
1898. ‡Coffey, George. 5 Harcourt-terrace, Dublin.
1881. *Coffin, Walter Harris, F.C.S. Passaic, Kew.
1896. *Coghill, Percy de G. 4 Sunnyside, Prince's Park, Liverpool.
1901. §Cohen, N. L. 11 Hyde Park-terrace, W.
1901. *Cohen, R. Waley, B.A. 11 Sussex-square, W.
1909. *Coke, Elmsley, M.Inst.C.E., F.G.S. 26 Low Pavement, Nottingham.
1906. *Coker, Professor Ernest George, M.A., D.Sc., F.R.S.E. City and Guilds of London Technical College, Finsbury, E.C.
1895. *Colby, James George Ernest, M.A., F.R.C.S. Malton, Yorkshire.
1895. *Colby, William Henry. Carregwen, Aberystwyth.
1893. §Cole, Grenville A. J., F.G.S., Professor of Geology in the Royal College of Science, Dublin.
1903. ‡Cole, Otto B. 551 Boylston-street, Boston, U.S.A.
1910. §Cole, Thomas Skelton. Westbury, Endcliffe-crescent, Sheffield.

Year of Election.

1897. §COLEMAN, Professor A. P., M.A., Ph.D., F.R.S. (Pres. C, 1910.). 476 Huron-street, Toronto, Canada.
1899. §Coleman, William, F.R.A.S. The Shrubbery, Buckland, Dover.
1899. ‡Collard, George. The Gables, Canterbury.
1892. ‡Collet, Miss Clara E. 7 Coleridge-road, N.
1887. ‡COLLIE, J. NORMAN, Ph.D., F.R.S., Professor of Organic Chemistry in the University of London. 16 Campden-grove, W.
1893. ‡Collinge, Walter E. The University, Birmingham.
1861. *Collingwood, J. Frederick, F.G.S. 5 Irene-road, Parson's Green, S.W.
1876. ‡COLLINS, J. H., F.G.S. Crinnis House, Par Station, Cornwall.
1865. *Collins, James Tertius. Churchfield, Edgbaston, Birmingham.
1910. *Collins, S. Hoare. 9 Cavendish-place, Newcastle-on-Tyne.
1905. ‡Collins, Rev. Spencer. The Rectory, Victoria West, Cape Colony.
1902. ‡Collins, T. R. Belfast Royal Academy, Belfast.
1910. *Colver, Robert, jun. Graham-road, Ranmoor, Sheffield.
1905. *Combs, Rev. Cyril W., M.A. Elverton, Castle-road, Newport, Isle of Wight.
1910. *Compton, Robert Harold, B.A. Gonville and Caius College, Cambridge.
1871. *Connor, Charles C. 10 College-gardens, Belfast.
1902. ‡Conway, A. W. 100 Leinster-road, Rathmines, Dublin.
1903. ‡Conway, R. Seymour, Litt.D., Professor of Latin in Owens College, Manchester.
1898. §Cook, Ernest H. 27 Berkeley-square, Clifton, Bristol.
1876. *COOKE, CONRAD W. The Pines, Langland-gardens, Hampstead, N.W.
1888. ‡Cooley, George Parkin. Constitutional Club, Nottingham.
1899. *Coomaraswamy, A. K., D.Sc., F.L.S., F.G.S. Broad Campden, Gloucestershire.
1902. *Coomaraswamy, Mrs. A. K. Broad Campden, Gloucestershire.
1903. §Cooper, Miss A. J. 22 St. John-street, Oxford.
1901. *Cooper, C. Forster, B.A. Trinity College, Cambridge.
1907. ‡Cooper, William. Education Offices, Becket-street, Derby.
1878. ‡Cope, Rev. S. W. Bramley, Leeds.
1904. *COPEMAN, S. MONCKTON, M.D., F.R.S. Local Government Board, Whitehall, S.W.
1909. §Copland, Mrs. A. J. Gleniffer, 50 Woodberry Down, N.
1904. *Copland, Miss Louisa. 10 Wynnstay-gardens, Kensington, W.
1905. ‡Corben, J. H. Education Department, Klerksdorp, Transvaal.
1901. ‡Corbett, A. Cameron, M.P. Thornliebank House, Glasgow.
1909. §Corbett, W. A. 207 Bank of Nova Scotia-buildings, Winnipeg, Canada.
1887. *Corcoran, Bryan. Fairlight, 22 Oliver-grove, South Norwood, S.E.
1894. §Corcoran, Miss Jessie R. Rotherfield Cottage, Bexhill-on-Sea.
1901. *Cormack, Professor J. D., B.Sc. University College, Gower-street, W.C.
1893. *Corner, Samuel, B.A., B.Sc. Abbotsford House, Waverley-street, Nottingham.
1889. ‡CORNISH, VAUGHAN, D.Sc., F.R.G.S. 31 Kensington Gardens-square, W.
1905. ‡Cornish-Bowden, A. H. Surveyor-General's Office, Cape Town.
1884. *Cornwallis, F. S. W., F.L.S. Linton Park, Maidstone.
1900. §Cortie, Rev. A. L., S.J., F.R.A.S. Stonyhurst College, Blackburn.
1905. ‡Cory, Professor G. E., M.A. Rhodes University College, Grahamstown, Cape Colony.
1909. *Cossar, G. C., M.A., F.G.S. Southview, Murrayfield, Edinburgh.
1910. §Cossar, James. 53 Belford-road, Edinburgh.
1908. *Costello, John Francis, B.A. The Rectory, Ballymackey, Nenagh, Ireland.

Year of Election.

1906. ‡Cotsworth, Moses B. Acomb, York.
1906. ‡*Cotter, J. R. 21 Mayfield-road, Terenure Park, Dublin.*
1874. *COTTERILL, J. H., M.A., F.R.S. Boleskine, Branksome Park, Bournemouth.
1908. ‡Cotton, Alderman W. F., D.L., J.P. Hollywood, Co. Dublin.
1905. ‡Cottrill, G. St. John. P.O. Box 4829, Johannesburg.
1908. ‡Courtenay, Colonel Arthur H., C.B., D.L. United Service Club, Dublin.
1896. ‡COURTNEY, Right Hon. Lord. (Pres. F, 1896.) 15 Cheyne-walk, Chelsea, S.W.
1905. ‡Cousens, R. L. P.O. Box 4261, Johannesburg.
1908. ‡Cowan, P. C., B.Sc., M.Inst.C.E. 33 Ailesbury-road, Dublin.
1872. *Cowan, Thomas William, F.L.S., F.G.S. Upcott House, Taunton, Somersetshire.
1903. ‡Coward, H. Knowle Board School, Bristol.
1900. §Cowburn, Henry. Dingle Head, Leigh, Lancashire.
1905. ‡Cowell, John Ray. P.O. Box 2141, Johannesburg.
1895. *COWELL, PHILIP H., M.A., D.Sc., F.R.S. 62 Shooters Hill-road, Blackheath, S.E.
1899. ‡Cowper-Coles, Sherard, Assoc.M.Inst.C.E. 82 Victoria-street, S.W.
1867. *Cox, Edward. Cardean, Meigle, N.B.
1909. §Cox, F. J. C. Anderson-avenue, Winnipeg, Canada.
1906. §Cox, S. Herbert, Professor of Mining in the Imperial College of Science and Technology, S.W.
1905. ‡Cox, W. H. Royal Observatory, Cape Town.
1908. ‡Craig, James, M.D. 18 Merrion-square North, Dublin.
1884. §CRAIGIE, Major P. G., C.B., F.S.S. (Pres. F, 1900; Council, 1908– .) Bronté House, Lympstone, Devon.
1906. ‡Craik, Sir Henry, K.C.B., LL.D., M.P. 5A Dean's-yard, Westminster, S.W.
1908. *Cramer, W., Ph.D., D.Sc. Physiological Department, The University, Edinburgh.
1906. ‡Cramp, William. Redthorn, Whalley-road, Manchester.
1905. *Cranswick, Wm. Franceys. 34 Boshof-road, Kimberley.
1906. ‡CRAVEN, HENRY. (Local Sec. 1906.) Clifton Green, York.
1887. **Craven, Thomas, J.P. Woodheyes-Park, Ashton-upon-Mersey.*
1905. ‡Crawford, Mrs. A. M. Marchmont, Rosebank, near Cape Town.
1910. *Crawford, O. G. S. The Grove, East Woodhay, Newbury.
1905. ‡Crawford, Professor Lawrence, M.A., D.Sc., F.R.S.E. South African College, Cape Town.
1871. *Crawford, William Caldwell, M.A. 1 Lockharton-gardens, Colinton-road, Edinburgh.
1905. ‡Crawford, W. C., jun. 1 Lockharton-gardens, Colinton-road, Edinburgh.
1871. *CRAWFORD AND BALCARRES, The Right Hon. the Earl of, K.T., LL.D., F.R.S., F.R.A.S. 2 Cavendish-square, W.; and Haigh Hall, Wigan.
1890. §Crawshaw, Charles B. Rufford Lodge, Dewsbury.
1883. *Crawshaw, Edward, F.R.G.S. 25 Tollington-park, N.
1885. §CREAK, Captain E. W., C.B., R.N., F.R.S. (Pres. E, 1903; Council, 1896–1903.) 9 Hervey-road, Blackheath, S.E.
1876. *Crewdson, Rev. Canon George. St. Mary's Vicarage, Windermere.
1887. *Crewdson, Theodore. Spurs, Styall, Handforth, Manchester.
1904. ‡Crilly, David. 7 Well-street, Paisley.
1880. *Crisp, Sir Frank, B.A., LL.B., F.L.S., F.G.S. 5 Lansdowne-road, Notting Hill, W.

Year of Election.

1908. §Crocker, J. Meadmore. Albion House, Bingley, Yorkshire.
1905. §Croft, Miss Mary. 17 Pelham-crescent, S.W.
1890. *Croft, W. B., M.A. Winchester College, Hampshire.
1908. ‡Crofts, D. G. Cadastral Survey, Nairobi, East African Protectorate.
1878. *Croke, John O'Byrne, M.A. Clouncagh, Ballingarry-Lacy, Co. Limerick.
1903. *Crompton, Holland. Oaklyn, Cross Oak-road, Berkhamsted.
1901. ‡CROMPTON, Colonel R. E., C.B., M.Inst.C.E. (Pres. G, 1901.) Kensington-court, W.
1887. ‡*CROOK, HENRY T., M.Inst.C.E. 9 Albert-square, Manchester.*
1898. §CROOKE, WILLIAM, B.A. (Pres. H, 1910; Council, 1910- .) Langton House, Charlton Kings, Cheltenham.
1865. §CROOKES, Sir WILLIAM, O.M., D.Sc., F.R.S., V.P.C.S. (PRESIDENT, 1898; Pres. B, 1886; Council, 1885–91.) 7 Kensington Park-gardens, W.
1879. ‡Crookes, Lady. 7 Kensington Park-gardens, W.
1897. *CROOKSHANK, E. M., M.B. Ashdown Forest, Forest Row, Sussex.
1909. ‡Crosby, Rev. E. H. Lewis, B.D. 36 Rutland-square, Dublin.
1905. ‡Crosfield, Hugh T. Walden, Coombe-road, Croydon.
1894. *Crosfield, Miss Margaret C. Undercroft, Reigate.
1870. *CROSFIELD, WILLIAM. 3 Fulwood-park, Liverpool.
1904. §Cross, Professor Charles R. Massachusetts Institute of Technology, Boston, U.S.A.
1890. ‡Cross, E. Richard, LL.B. Harwood House, New Parks-crescent, Scarborough.
1905. §Cross, Robert. 13 Moray-place, Edinburgh.
1904. *CROSSLEY, A. W., D.Sc., Ph.D., F.R.S., Professor of Chemistry to the Pharmaceutical Society of Great Britain. 10 Crediton-road, West Hampstead, N.W.
1908. ‡Crossley, F. W. 30 Molesworth-street, Dublin.
1887. *Crossley, Sir William J., Bart., M.P. Glenfield, Bowdon, Cheshire.
1894. *Crosweller, William Thomas, F.Z.S., F.I.Inst. Kent Lodge, Sidcup, Kent.
1897. *Crosweller, Mrs. W. T. Kent Lodge, Sidcup, Kent.
1890. *Crowley, Ralph Henry, M.D. Sollershott W., Letchworth.
1910. §Crowther, Dr. C., M.A. The University, Leeds.
1910. *Crowther, James Arnold. St. John's College, Cambridge.
1883. *CULVERWELL, EDWARD P., M.A., Professor of Education in Trinity College, Dublin.
1883. ‡Culverwell, T. J. H. Litfield House, Clifton, Bristol.
1898. ‡Cundall, J. Tudor. 1 Dean Park-crescent, Edinburgh.
1861. *Cunliffe, Edward Thomas. The Parsonage, Handforth, Manchester.
1861. *Cunliffe, Peter Gibson. Dunedin, Handforth, Manchester.
1905. ‡Cunningham, Miss A. 2 St. Paul's-road, Cambridge.
1882. *CUNNINGHAM, Lieut.-Colonel ALLAN, R.E., A.I.C.E. 20 Essex-villas, Kensington, W.
1905. ‡Cunningham, Andrew. Earlsferry, Campground-road, Mowbray, South Africa.
1885. ‡CUNNINGHAM, J. T., B.A. Biological Laboratory, Plymouth.
1869. ‡CUNNINGHAM, ROBERT O., M.D., F.L.S., Professor of Natural History in Queen's College, Belfast.
1883. *CUNNINGHAM, Rev. W., D.D., D.Sc. (Pres. F, 1891, 1905.) Trinity College, Cambridge.
1892. ‡Cunningham-Craig, E. H., B.A., F.G.S. 14A Dublin-street, Edinburgh.
1900. *Cunnington, William A., M.A., Ph.D., F.Z.S. 25 Orlando-road, Clapham Common, S.W.

Year of Election.

1908. ‡Currelly, C. T., M.A., F.R.G.S. United Empire Club, 117 Piccadilly, W.
1892. *Currie, James, M.A., F.R.S.E. Larkfield, Wardie-road, Edinburgh.
1905. ‡Currie, Dr. O. J. Manor House, Mowbray, Cape Town.
1905. ‡Currie, W. P. P.O. Box 2010, Johannesburg.
1902. ‡Curry, Professor M., M.Inst.C.E. 5 King's-gardens, Hove.
1883. ‡Cushing, Mrs. M. Rosslynlee, Woodside Green, South Norwood, S.E.
1881. §Cushing, Thomas, F.R.A.S. Rosslynlee, Woodside Green, South Norwood, S.E.
1907. ‡Cushny, Arthur R., M.D., F.R.S., Professor of Pharmacology in University College, Gower-street, W.C.

1910. §Dakin, Dr. W. J. The University, Liverpool.
1898. *Dalby, W. E., M.A., B.Sc., M.Inst.C.E. (Pres. G, 1910), Professor of Civil and Mechanical Engineering in the City and Guilds of London Institute, Exhibition-road, S.W.
1889. *Dale, Miss Elizabeth. Garth Cottage, Oxford-road, Cambridge.
1906. §Dale, William, F.S.A., F.G.S. The Lawn, Archer's-road, Southampton.
1907. ‡Dalgliesh, Richard, J.P., D.L. Ashfordby Place, near Melton Mowbray.
1904. *Dalton, J. H. C., M.D. The Plot, Adams-road, Cambridge.
1862. ‡Danby, T. W., M.A., F.G.S. The Crouch, Seaford, Sussex.
1905. ‡Daniel, Miss A. M. 3 St. John's-terrace, Weston-super-Mare.
1901. ‡Daniell, G. F., B.Sc. Woodberry, Oakleigh Park, N.
1896. §Danson, F. C. Tower-buildings, Water-street, Liverpool.
1849. *Danson, Joseph. Montreal, Canada.
1897. §Darbishire, F. V., B.A., Ph.D. South-Eastern Agricultural College, Wye, Kent.
1903. ‡Darbishire, Dr. Otto V. The University, Manchester.
1904. *Darwin, Charles Galton. Newnham Grange, Cambridge.
1899. *Darwin, Erasmus. The Orchard, Huntingdon-road, Cambridge.
1882. *Darwin, Francis, M.A., M.B., LL.D., D.Sc., F.R.S., F.L.S. (President, 1908; Pres. D, 1891; Pres. K, 1904; Council, 1882–84, 1897–1901.) 13 Madingley-road, Cambridge.
1881. *Darwin, Sir George Howard, K.C.B., M.A., LL.D., F.R.S., F.R.A.S. (President, 1905; Pres. A, 1886; Council, 1886–1892), Plumian Professor of Astronomy and Experimental Philosophy in the University of Cambridge. Newnham Grange, Cambridge.
1905. ‡Darwin, Lady. Newnham Grange, Cambridge.
1878. *Darwin, Horace, M.A., F.R.S. The Orchard, Huntingdon-road, Cambridge.
1894. *Darwin, Major Leonard, Pres. R.G.S. (Pres. E, 1896; Council, 1899–1905.) 12 Egerton-place, South Kensington, S.W.
1882. ‡Darwin, W. E., B.A., F.G.S. 11 Egerton-place, S.W.
1910. §Dauncey, Mrs. Thursby. Lady Stewert, Heath-road, Weybridge.
1908. ‡Davey, H. 15 Victoria-road, Brighton.
1880. *Davey, Henry, M.Inst.C.E. Conaways, Ewell, Surrey.
1884. ‡David, A. J., B.A., LL.B. 4 Harcourt-buildings, Temple, E.C.
1904. §Davidge, H. T., B.Sc., Professor of Electricity in the Ordnance College, Woolwich.
1909. ‡Davidson, A. R. 150 Stradbrooke-place, Winnipeg, Canada.
1902. *Davidson, S. C. Seacourt, Bangor, Co. Down.

Year of Election.

1910. *Davie, Robert C., M.A., B.Sc. 16 Ruthven-street, Kelvinside, Glasgow.
1887. *Davies, H. Rees. Treborth, Bangor, North Wales.
1904. §Davies, Henry N., F.G.S. St. Chad's, Weston-super-Mare.
1906. ‡Davies, S. H. Ryecroft, New Earswick, York.
1893. *Davies, Rev. T. Witton, B.A., Ph.D., D.D., Professor of Semitic Languages in University College, Bangor, North Wales.
1896. *Davies, Thomas Wilberforce, F.G.S. 41 Park-place, Cardiff.
1870. *Davis, A. S. St. George's School, Roundhay, near Leeds.
1873. *Davis, Alfred. 37 Ladbroke-grove, W.
1905. ‡Davis, C. R. S. National Bank-buildings, Johannesburg.
1896. *Davis, John Henry Grant. The Hawthorns, Sutton-road, Walsall.
1910. §Davis, John King. 2 Brockenhurst Green-street, Jersey.
1905. §Davis, Luther. P.O. Box 898, Johannesburg.
1885. *Davis, Rev. Rudolf. Mornington, Elmbridge-road, Gloucester.
1905. ‡Davy, Mrs. Alice Burtt. P.O. Box 434, Pretoria.
1905. ‡Davy, Joseph Burtt, F.R.G.S., F.L.S. P.O. Box 434, Pretoria.
1864. ‡DAWKINS, W. BOYD, D.Sc., F.R.S., F.S.A., F.G.S. (Pres. C, 1888; Council, 1882–88.) Fallowfield House, Fallowfield, Manchester.
1885. *Dawson, Lieut.-Colonel H. P., R.A. Hartlington Hall, Burnsall, Skipton-in-Craven.
1901. *Dawson, P. The Acre, Maryhill, Glasgow.
1905. ‡Dawson, Mrs. The Acre, Maryhill, Glasgow.
1884. ‡DAWSON, SAMUEL. (Local Sec. 1884.) 258 University-street, Montreal, Canada.
1906. §Dawson, William Clarke. 16 Parliament-street, Hull.
1859. *Dawson, Captain W. G. 31 King's-gardens, West End-lane, N.W.
1909. ‡Day, Miss M. Edith. 290 Portage-avenue, Winnipeg, Canada.
1900. ‡Deacon, M. Whittington House, near Chesterfield.
1909. §Dean, George, F.R.G.S. 5 Wordsworth-mansions, Queen's Club-gardens, W.
1901. *Deasy, Captain H. H. P. 24 Evelyn-gardens, S.W.
1884. *Debenham, Frank, F.S.S. 1 Fitzjohn's-avenue, N.W.
1866. ‡DEBUS, HEINRICH, Ph.D., F.R.S., F.C.S. (Pres. B, 1869; Council, 1870–75.) 4 Schlangenweg, Cassel, Hessen.
1893. *Deeley, R. M., M.Inst.C.E., F.G.S. Inglewood, Longcroft-avenue, Harpenden, Herts.
1878. ‡DELANY, Very Rev. WILLIAM, LL.D. University College, Dublin.
1908. *Delf, Miss E. M. Westfield College, Hampstead, N.W.
1907. ‡De Lisle, Mrs. Edwin. Charnwood Lodge, Coalville, Leicestershire.
1896. ‡Dempster, John. Tynron, Noctorum, Birkenhead.
1902. ‡Dendy, Arthur, D.Sc., F.R.S., F.L.S., Professor of Zoology in King's College, London, W.C.
1908. ‡Dennehy, W. F. 23 Leeson-park, Dublin.
1889. §DENNY, ALFRED, M.Sc., F.L.S., Professor of Biology in the University of Sheffield.
1905. ‡Denny, G. A. 603–4 Consolidated-buildings, Fox-street, Johannesburg.
1909. §Dent, Edward, M.A. 2 Carlos-place, W.
1874. *Derham, Walter, M.A., LL.M., F.G.S. Junior Carlton Club, Pall Mall, S.W.
1907. *Desch, Cecil H., D.Sc., Ph.D. 9 Spring-gardens, North Kelvinside, Glasgow.
1908. §Despard, Miss Kathleen M. 6 Sutton Court-mansions, Grove Park-terrace, Chiswick.
1894. *Deverell, F. H. 7 Grote's-place, Blackheath, S.E.

Year of Election.

1868. *DEWAR, Sir JAMES, M.A., LL.D., D.Sc., F.R.S., F.R.S.E., V.P.C.S., Fullerian Professor of Chemistry in the Royal Institution, London, and Jacksonian Professor of Natural and Experimental Philosophy in the University of Cambridge. (PRESIDENT, 1902; Pres. B, 1879; Council, 1883–88.) 1 Scroope-terrace, Cambridge.
1881. ‡Dewar, Lady. 1 Scroope-terrace, Cambridge.
1884. *Dewar, William, M.A. Horton House, Rugby.
1905. ‡*Dewhirst, Miss May. Pembroke House, Oxford-road, Colchester.*
1901. ‡Dick, George Handasyde. 31 Hamilton-drive, Hillhead, Glasgow.
1908. §Dicks, Henry. Haslecourt, Horsell, Woking.
1904. §Dickson, Charles Scott, K.C., LL.D. Carlton Club, Pall Mall, S.W.
1881. ‡Dickson, Edmund, M.A., F.G.S. Claughton House, Garstang, R.S.O., Lancashire.
1887. §DICKSON, H. N., D.Sc., F.R.S.E., F.R.G.S. The Lawn, Upper Redlands-road, Reading.
1902. §Dickson, James D. Hamilton, M.A., F.R.S.E. 6 Cranmer-road, Cambridge.
1862. *DILKE, The Right Hon. Sir CHARLES WENTWORTH, Bart., M.P., F.R.G.S. 76 Sloane-street, S.W.
1877. ‡Dillon, James, M.Inst.C.E. 36 Dawson-street, Dublin.
1908. ‡Dines, J. S. 4 Larkfield-road, Richmond, Surrey.
1901. §Dines, W. H., B.A., F.R.S. Pyrton Hill, Watlington.
1900. §DIVERS, Professor EDWARD, M.D., D.Sc., F.R.S. (Pres. B, 1902.) 3 Canning-place, Palace Gate, W.
1898. *Dix, John William S. Hampton Lodge, Durdham Down, Clifton, Bristol.
1905. §Dixey, F. A., M.A., M.D., F.R.S., Wadham College, Oxford.
1899. *DIXON, A. C., D.Sc., F.R.S., Professor of Mathematics in Queen's University, Belfast. Hurstwood, Malone Park, Belfast.
1874. *DIXON, A. E., M.D., Professor of Chemistry in Queen's College, Cork.
1900. ‡Dixon, A. Francis, Sc.D., Professor of Anatomy in the University of Dublin.
1905. ‡Dixon, Miss E. K. Fern Bank, St. Bees, Cumberland.
1908. ‡Dixon, Edward K., M.E., M.Inst.C.E. Castlebar, Co. Mayo.
1888. ‡Dixon, Edward T. Racketts, Hythe, Hampshire.
1908. *DIXON, ERNEST, B.Sc., F.G.S. The Museum, Jermyn-street, S.W.
1900. *Dixon, Major George, M.A. Fern Bank, St. Bees, Cumberland.
1879. *DIXON, HAROLD B., M.A., F.R.S., F.C.S. (Pres. B, 1894), Professor of Chemistry in the Victoria University, Manchester.
1902. ‡Dixon, Henry H., D.Sc., F.R.S., Professor of Botany in the University of Dublin. Clevedon, Temple-road, Dublin.
1908. *Dixon, Walter, F.R.M.S. Derwent, 30 Kelvinside-gardens, Glasgow.
1907. *Dixon, Professor Walter E. The Museums, Cambridge.
1902. ‡Dixon, W. V. Scotch Quarter, Carrickfergus.
1896. §Dixon-Nuttall, F. R. Ingleholme, Eccleston Park, Prescot.
1890. ‡Dobbie, James J., D.Sc., LL.D., F.R.S., Principal of the Government Laboratories, 13 Clement's Inn-passage, W.C.
1885. §Dobbin, Leonard, Ph.D. The University, Edinburgh.
1860. *Dobbs, Archibald Edward, M.A. Castle Dobbs, Carrickfergus, Co. Antrim.
1902. ‡Dobbs, F. W. 2 Willowbrook, Eton, Windsor.
1905. ‡Dobson, Professor J. H. Transvaal Technical Institute, Johannesburg.

Year of
Election.

1908. ‡DODD, Hon. Mr. Justice. 26 Fitzwilliam-square, Dublin.
1876. ‡Dodds, J. M. St. Peter's College, Cambridge.
1905. ‡Dodds, Dr. W. J. Valkenberg, Mowbray, Cape Colony.
1904. ‡Doncaster, Leonard, M.A. King's College, Cambridge.
1896. ‡Donnan, F. E. Ardenmore-terrace, Holywood, Ireland.
1901. ‡Donnan, F. G., M.A., Ph.D., Professor of Physical Chemistry. The University, Liverpool.
1905. ‡Donnan, H. Allandale, Claremont, Cape Colony.
1905. ‡Donner, Arthur. Helsingfors, Finland.
1905. §Dornan, Rev. S. S. P.O. Box 510, Bulawayo, South Rhodesia, South Africa.
1863. *Doughty, Charles Montagu. 26 Grange-road, Eastbourne.
1909. ‡Douglas, A. J., M.D. City Health Department, Winnipeg, Canada.
1909. *Douglas, James. 99 John-street, New York, U.S.A.
1905. ‡Douglas-McMillan, Mrs. A. 31 Ford-street, Jeppestown, Transvaal.
1884. ‡Dove, Miss Frances. Wycombe Abbey School, Buckinghamshire.
1903. ‡Dow, Miss Agnes R. 81 Park-mansions, Knightsbridge, S.W.
1884. *Dowling, D. J. Sycamore, Clive-avenue, Hastings.
1865. *Dowson, E. Theodore, F.R.M.S. Geldeston, near Beccles, Suffolk.
1881. *Dowson, J. Emerson, M.Inst.C.E. 11 Embankment-gardens, Chelsea, S.W.
1892. *Dreghorn, David, J.P. Greenwood, Pollokshields, Glasgow.
1905. ‡Drew, H. W., M.B., M.R.C.S. Mocollup Castle, Ballyduff, S.O., Co. Waterford.
1906. *Drew, Joseph Webster, M.A., LL.M. Fashoda, Scarborough.
1906. *Drew, Mrs. Fashoda, Scarborough.
1908. §Droop, J. P. 11 Cleveland-gardens, Hyde Park, W.
1893. §DRUCE, G. CLARIDGE, M.A., F.L.S. (Local Sec. 1894.) Yardley Lodge, 9 Crick-road, Oxford.
1909. *Drugman, Julien, Ph.D., M.Sc. Maison Négrin, La Bocca, Cannes, France.
1905. ‡Drury, H. P.O. Box 2305, Johannesburg.
1905. ‡Drury, Mrs. H. P.O. Box 2305, Johannesburg.
1907. §Drysdale, Charles V., D.Sc. Northampton Institute, Clerkenwell, E.C.
1892. ‡Du Bois, Professor Dr. H. Herwarthstrasse 4, Berlin, N.W.
1856. *DUCIE, The Right Hon. HENRY JOHN REYNOLDS MORETON, Earl of, F.R.S., F.G.S. 16 Portman-square, W.
1870. ‡Duckworth, Henry, F.L.S., F.G.S. 7 Grey Friars, Chester.
1900. *Duckworth, W. L. H., M.D., Sc.D. Jesus College, Cambridge.
1895. *Duddell, William, F.R.S. 47 Hans-place, S.W.
1906. ‡Dudgeon, Gerald C., Superintendent of Agriculture for British West Africa. Bathurst, Gambia, British West Africa.
1904. *Duffield, W. Geoffrey. University College, Reading.
1890. ‡Dufton, S. F. Trinity College, Cambridge.
1909. ‡Duncan, D. M., M.A. 83 Spence-street, Winnipeg, Canada.
1891. *Duncan, Sir John, J.P. 'South Wales Daily News' Office, Cardiff.
1910. §Dunn, Rev. J. Road Hill Vicarage, Bath.
1876. ‡Dunnachie, James. 48 West Regent-street, Glasgow.
1884. ‡Dunnington, Professor F. P. University of Virginia, Charlottesville, Virginia, U.S.A.
1893. *Dunstan, M. J. R., Principal of the South-Eastern Agricultural College, Wye, Kent.
1891. ‡Dunstan, Mrs. South-Eastern Agricultural College, Wye, Kent.
1885. *DUNSTAN, Professor WYNDHAM, M.A., LL.D., F.R.S., V.P.C.S. (Pres. B, 1906; Council, 1905–08), Director of the Imperial Institute, S.W.

Year of Election.

1905. §Dutton, C. L. O'Brien. High Commissioner's Office, Johannesburg.
1910. §Dutton, F. V., B.Sc. County Agricultural Laboratories, Richmond-road, Exeter.
1895. *Dwerryhouse, Arthur R., D.Sc., F.G.S. Deraness, Deramore Park, Belfast.
1885. *Dyer, Henry, M.A., D.Sc. 8 Highburgh-terrace, Dowanhill, Glasgow.
1895. §Dymond, Thomas S., F.C.S. Savile Club, Piccadilly, W.
1905. *Dyson, F. W., M.A., F.R.S. (Council, 1905–), Astronomer Royal. Royal Observatory, Greenwich, S.E.
1910. §Dyson, W. H. Maltby Colliery, near Rotherham, Yorkshire.

1905. ‡Earp, E. J. P.O. Box 538, Cape Town.
1899. ‡East, W. H. Municipal School of Art, Science, and Technology, Dover.
1909. *Easterbrook, C. C., M.A., M.D. Crichton Royal Institution, Dumfries.
1893. *Ebbs, Alfred B. Northumberland-alley, Fenchurch-street, E.C.
1906. *Ebbs, Mrs. A. B. Tuborg, Durham-avenue, Bromley, Kent.
1909. ‡Eccles, J. R. Gresham's School, Holt, Norfolk.
1903. ‡Eccles, W. H., D.Sc. 16 Worfield-street, Battersea, S.W.
1908. *Eddington, A. S., B.A., M.Sc. Royal Observatory, Greenwich, S.E.
1870. *Eddison, John Edwin, M.D., M.R.C.S. The Lodge, Adel, Leeds.
1858. *Eddy, James Ray, F.G.S. The Grange, Carleton, Skipton.
1884. *Edgell, Rev. R. Arnold, M.A. Beckley Rectory, East Sussex.
1887. §Edgeworth, F. Y., M.A., D.C.L., F.S.S. (Pres. F, 1889; Council, 1879–86, 1891–98), Professor of Political Economy in the University of Oxford. All Souls College, Oxford.
1870. *Edmonds, F. B. 6 Clement's Inn, W.C.
1883. ‡Edmonds, William. Wiscombe Park, Colyton, Devon.
1888. *Edmunds, Henry. Antron, 71 Upper Tulse-hill, S.W.
1884. *Edmunds, James, M.D. 23 Sussex-square, Kemp Town, Brighton.
1901. *Edridge-Green, F. W., M.D., F.R.C.S. Hendon Grove, Hendon, N.W.
1899. §Edwards, E. J., Assoc.M.Inst.C.E. 290 Trinity-road, Wandsworth, S.W.
1903. ‡Edwards, Mrs. Emily. Norley Grange, 73 Leyland-road, Southport.
1903. ‡Edwards, Francis. Norley Grange, 73 Leyland-road, Southport.
1903. ‡Edwards, Miss Marion K. Norley Grange, 73 Leyland-road, Southport.
1901. ‡Eggar, W. D. Eton College, Windsor.
1909. ‡Eggertson, Arni. 120 Emily-street, Winnipeg, Canada.
1909. §Ehrenborg, G. B. 518 Winch-building, Vancouver, B.C., Canada.
1907. *Elderton, W. Palin. 74 Mount Nod-road, Streatham, S.W.
1890. §Elford, Percy. 115 Woodstock-road, Oxford.
1901. *Elles, Miss Gertrude L., D.Sc. Newnham College, Cambridge.
1904. ‡Elliot, Miss Agnes I. M. Newnham College, Cambridge.
1904 ‡Elliot, R. H. Clifton Park, Kelso, N.B.
1904 ‡*Elliot, T. R. B. Holme Park, Rotherfield, Sussex.*
1891. ‡Elliott, A. C., D.Sc., M.Inst.C.E., Professor of Engineering in University College, Cardiff. 2 Plasturton-avenue, Cardiff.
1905. ‡Elliott, C. C., M.D. Church-square, Cape Town.

Year of Election.

1883. *ELLIOTT, EDWIN BAILEY, M.A., F.R.S., F.R.A.S., Waynflete Professor of Pure Mathematics in the University of Oxford. 4 Bardwell-road, Oxford.
Elliott, John Fogg. Elvet Hill, Durham.
1906. *Ellis, David, D.Sc., Ph.D. Technical College, Glasgow.
1875. *Ellis, H. D. 12 Gloucester-terrace, Hyde Park, W.
1906. §ELLIS, HERBERT. 120 Regent-road, Leicester.
1880. *ELLIS, JOHN HENRY. (Local Sec. 1883.) 10 The Crescent, Plymouth.
1891. §Ellis, Miss M. A. 14 Wellington-square, Oxford.
1906. ‡ELMHIRST, CHARLES E. (Local Sec. 1906.) 29 Mount-vale, York.
1910. §Elmhirst, Richard. Marine Biological Station, Millport.
1884. ‡Emery, Albert H. Stamford, Connecticut, U.S.A.
1869. *Enys, John Davies. Enys, Penryn, Cornwall.
1862. *ESSON, WILLIAM, M.A., F.R.S., F.R.A.S., Savilian Professor of Geometry in the University of Oxford. 13 Bradmore-road, Oxford.
1887. *Estcourt, Charles, F.I.C. 5 Seymour-grove, Old Trafford, Manchester.
1887. *Estcourt, P. A., F.C.S., F.I.C. 5 Seymour-grove, Old Trafford, Manchester.
1911. §ETHERTON, G. HAMMOND. (LOCAL SECRETARY, 1911.) Town Hall, Portsmouth.
1897. *Evans, Lady. Britwell, Berkhamsted, Herts.
1889. *EVANS, A. H., M.A. 9 Harvey-road, Cambridge.
1905. ‡Evans, Mrs. A. H. 9 Harvey-road, Cambridge.
1870. *EVANS, ARTHUR JOHN, M.A., LL.D., F.R.S., F.S.A. (Pres. H, 1896.) Youlbury, Abingdon.
1908. ‡Evans, Rev. Henry, D.D., Commissioner of National Education, Ireland. Blackrock, Co. Dublin.
1887. *Evans, Mrs. Isabel. Hoghton Hall, Hoghton, near Preston.
1883. *Evans, Mrs. James C. Casewell Lodge, Llanwrtyd Wells, South Wales.
1910. *Evans, John W., D.Sc., LL.B., F.G.S. 75 Craven Park-road, Harlesden, N.W.
1885. *Evans, Percy Bagnall. The Spring, Kenilworth.
1905. ‡Evans, R. O. Ll. Broom Hall, Chwilog, R.S.O., Carnarvonshire.
1905. ‡Evans, T. H. 9 Harvey-road, Cambridge.
1910. §Evans, T. J. The University, Sheffield.
1905. ‡Evans, Thomas H. P.O. Box 1276, Johannesburg.
1865. *Evans, William. The Spring, Kenilworth.
1909. ‡EVANS, W. SANFORD, M.A. (Local Sec. 1909). 43 Edmonton-street, Winnipeg.
1903. ‡Evatt, E. J., M.B. 8 Kyveilog-street, Cardiff.
1902. *Everett, Percy W. Oaklands, Elstree, Hertfordshire.
1872. ‡EVERSLEY, Right Hon. Lord, F.R.S. (Pres. F, 1879; Council, 1878–80.) 18 Bryanston-square, W.
1883. ‡Eves, Miss Florence. Uxbridge.
1881. ‡EWART, J. COSSAR, M.D., F.R.S. (Pres. D, 1901), Professor of Natural History in the University of Edinburgh.
1874. ‡EWART, Sir W. QUARTUS, Bart. (Local Sec. 1874.) Glenmachan, Belfast.
1876. *EWING, JAMES ALFRED, C.B., M.A., LL.D., F.R.S., F.R.S.E., M.Inst.C.E. (Pres. G, 1906), Director of Naval Education, Admiralty, S.W. Froghole, Edenbridge, Kent.
1903. §Ewing, Peter, F.L.S. The Frond, Uddingston, Glasgow.
1884. *Eyerman, John, F.Z.S. Oakhurst, Easton, Pennsylvania, U.S.A.

Year of Election.

1905. ‡Eyre, Dr. G. G. Claremont, Cape Colony.
Eyton, Charles. Hendred House, Abingdon.

1906. *Faber, George D. 14 Grosvenor-square, W.
1901. *Fairgrieve, M. McCallum. 67 Great King-street, Edinburgh.
1865. *Fairley, Thomas, F.R.S.E., F.C.S. 8 Newton-grove, Leeds.
1910. §Falconer, J. D. The Limes, Little Berkhamsted, Hertford.
1908. ‡Falconer, Robert A., M.A. 44 Merrion-square, Dublin.
1896. §Falk, Herman John, M.A. Thorshill, West Kirby, Cheshire.
1902. §Fallaize, E. N., M.A. Vinchelez, Chase Court-gardens, Windmill-hill, Enfield.
1907. *Fantham, H. B., D.Sc. New Museums, Cambridge.
1902. §Faren, William. 11 Mount Charles, Belfast.
1892. *Farmer, J. Bretland, M.A., F.R.S., F.L.S. (Pres. K, 1907.) Shirley Holms, Gerrards Cross.
1886. ‡Farncombe, Joseph, J.P. Saltwood, Spencer-road, Eastbourne.
1897. *Farnworth, Mrs. Ernest. Broadlands, Goldthorn Hill, Wolverhampton.
1904. ‡Farnworth, Miss Olive. Broadlands, Goldthorn Hill, Wolverhampton.
1885. *Farquharson, Mrs. R. F. O. Tillydrine, Kincardine O'Neil, N.B.
1905. ‡Farrar, Edward. P.O. Box 1242, Johannesburg.
1904. §Farrer, Sir William. 18 Upper Brook-street, W.
1903. §Faulkner, Joseph M. 17 Great Ducie-street, Strangeways, Manchester.
1890. *Fawcett, F. B. University College, Bristol.
1906. §Fawcett, Henry Hargreave. 20 Margaret-street, Cavendish-square, W.
1900. ‡Fawcett, J. E., J.P. (Local Sec. 1900.) Low Royd, Apperley Bridge, Bradford.
1902. *Fawsitt, C. E., Ph.D., Professor of Chemistry in the University of Sydney, New South Wales.
1909. *Fay, Charles Ryle, M.A. Christ's College, Cambridge.
1906. *Fearnsides, Edwin G., M.A., M.B., B.Sc. London Hospital, E.
1901. *Fearnsides, W. G., M.A., F.G.S. Sidney Sussex College, Cambridge.
1905. §Feilden, Colonel H. W., C.B., F.R.G.S., F.G.S. Burwash, Sussex.
1900. *Fennell, William John. Deramore Drive, Belfast.
1904. ‡Fenton, H. J. H., M.A., F.R.S. 19 Brookside, Cambridge.
1871. *Ferguson, John, M.A., LL.D., F.R.S.E., F.S.A., F.C.S., Professor of Chemistry in the University of Glasgow.
1896. *Ferguson, Hon. John, C.M.G. Naseby House, Newera Elliya, Ceylon.
1901. ‡Ferguson, R. W. Municipal Technical School, the Gamble Institute, St. Helens, Lancashire.
1863. *Fernie, John. Box No. 2, Hutchinson, Kansas, U.S.A.
1910. *Ferranti, S. Zae. Grindleford, near Sheffield.
1905. ‡*Ferrar, J. E. Sidney Sussex College, Cambridge.*
1905. *Ferrar, H. T., M.A., F.G.S. Geological Survey of Egypt, Giza, Egypt.
1873. ‡Ferrier, Sir David, M.A., M.D., LL.D., F.R.S., Professor of Neuro-Pathology in King's College, London. 34 Cavendish-square, W.
1909. ‡Fetherstonhaugh, Professor Edward P., B.Sc. 119 Betourney-street, Winnipeg, Canada.
1882. §Fewings, James, B.A., B.Sc. King Edward VI. Grammar School, Southampton.

Year of Election.

1897. ‡Field, George Wilton, Ph.D. Room 158, State House, Boston, Massachusetts, U.S.A.
1907. §Fields, Professor J. C. The University, Toronto, Canada.
1906. §Filon, L. N. G., D.Sc., F.R.S. Vega, Blenheim Park-road, Croydon.
1883. *Finch, Gerard B., M.A. Howes Close, Cambridge.
1905. ‡Fincham, G. H. Hopewell, Invami, Cape Colony.
1905. §Findlay, Alexander, M.A., Ph.D., D.Sc., Lecturer on Physical Chemistry in the University of Birmingham.
1904. *Findlay, J. J., Ph.D., Professor of Education in the Victoria University, Manchester. Ruperra, Victoria Park, Manchester.
1902. §Finnegan, J., M.A., B.Sc. Kelvin House, Botanic-avenue, Belfast.
1902. ‡Fisher, J. R. Cranfield, Fortwilliam Park, Belfast.
1909. §Fisher, James, K.C. 216 Portage-avenue, Winnipeg, Canada.
1869. ‡Fisher, Rev. Osmond, M.A., F.G.S. Harlton Rectory, near Cambridge.
1875. *Fisher, W. W., M.A., F.C.S. 5 St. Margaret's-road, Oxford.
1887. *Fison, Alfred H., D.Sc. 47 Dartmouth-road, Willesden Green, N.W.
1871. *Fison, Sir Frederick W., Bart., M.A., F.C.S. 64 Pont-street, S.W.
1883. ‡Fitch, Rev. J. J. 5 Chambres-road, Southport.
1885. *FitzGerald, Professor Maurice, B.A. (Local Sec. 1902.) 32 Eglantine-avenue, Belfast.
1894. ‡Fitzmaurice, Maurice, C.M.G., M.Inst.C.E. London County Council, Spring-gardens, S.W.
1888. *Fitzpatrick, Rev. Thomas C., President of Queens' College, Cambridge.
1904. ‡Flather, J. H., M.A. Camden House, 90 Hills-road, Cambridge.
1904. ‡Fleming, James. 25 Kelvinside-terrace South, Glasgow.
1892. ‡Fletcher, George, F.G.S. 55 Pembroke-road, Dublin.
1888. *Fletcher, Lazarus, M.A., F.R.S., F.G.S., F.C.S. (Pres. C, 1894), Director of the Natural History Museum, Cromwell-road, S.W. 35 Woodville-gardens, Ealing, W.
1908. *Fletcher, W. H. B. Aldwick Manor, Bognor, Sussex.
1901. ‡Flett, J. S., M.A., D.Sc., F.R.S.E. 28 Jermyn-street, S.W.
1906. *Fleure, H. J., D.Sc., Professor of Zoology and Geology in University College, Aberystwyth.
1905. *Flint, Rev. W., D.D. Houses of Parliament, Cape Town.
1889. ‡Flower, Lady. 26 Stanhope-gardens, S.W.
1905. ‡Flowers, Frank. United Buildings, Foxburgh, Johannesburg.
1890. *Flux, A. W., M.A. Board of Trade, Gwydyr House, Whitehall, S.W.
1877. ‡Foale, William. The Croft, Madeira Park, Tunbridge Wells.
1903. ‡Foord-Kelcey, W., Professor of Mathematics in the Royal Military Academy, Woolwich. The Shrubbery, Shooter's Hill, S.E.
1906. §Forbes, Charles Mansfeldt. 1 Oriel-crescent, Scarborough.
1873. *Forbes, George, M.A., F.R.S., F.R.S.E., M.Inst.C.E. 11 Little College-street, Westminster, S.W.
1883. ‡Forbes, Henry O., LL.D., F.Z.S., Director of Museums for the Corporation of Liverpool. The Museum, Liverpool.
1905. §Forbes, Major W. Lachlan. Army and Navy Club, London, S.W.
1890. ‡Ford, J. Rawlinson. (Local Sec. 1890.) Quarry Dene, Weetwood-lane, Leeds.
1875. *Fordham, Sir Herbert George. Odsey, Ashwell, Baldock, Herts.
1909. ‡Forget, The Hon. A. E. Regina, Saskatchewan, Canada.

Year of Election.

1887. ‡FORREST, The Right Hon. Sir JOHN, G.C.M.G., F.R.G.S., F.G.S. Perth, Western Australia.
1902. *Forster, M. O., Ph.D., D.Sc., F.R.S. Imperial College of Science and Technology, S.W.
1883. ‡FORSYTH, A. R., M.A., D.Sc., F.R.S. (Pres. A, 1897, 1905; Council, 1907-09.) Belgrave-mansions, Grosvenor-gardens, S.W.
1911. §FOSTER, Alderman T. SCOTT, J.P. (LOCAL TREASURER, 1911.) Town Hall, Portsmouth.
1857. *FOSTER, GEORGE CAREY, B.A., LL.D., D.Sc., F.R.S. (GENERAL TREASURER, 1898-1904; Pres. A, 1877; Council, 1871-76, 1877-82). Ladywalk, Rickmansworth.
1908. *Foster, John Arnold. 11 Hills-place, Oxford Circus, W.
1901. §Foster, T. Gregory, Ph.D., Principal of University College, London. Chester-road, Northwood, Middlesex.
1903. ‡Fourcade, H. G. P.O., Storms River, Humansdorp, Cape Colony.
1905. §Fowlds, Hiram. 65 Devonshire-street, Keighley, Yorkshire.
1909. §Fowlds, Mrs. 65 Devonshire-street, Keighley, Yorkshire.
1906. §Fowler, Oliver H., M.R.C.S. Ashcroft House, Cirencester.
1883. *Fox, Charles. The Pynes, Warlingham-on-the-Hill, Surrey.
1883. ‡Fox, Sir CHARLES DOUGLAS, M.Inst.C.E. (Pres. G, 1896.) Cross Keys House, 56 Moorgate-street, E.C.
1904. *Fox, Charles J. J., B.Sc., Ph.D., Professor of Chemistry in the Presidency College of Science, Poona, India.
1904. §Fox, F. Douglas, M.A., M.Inst.C.E. 19 The Square, Kensington, W.
1905. ‡Fox, Mrs. F. Douglas. 19 The Square, Kensington, W.
1883. ‡Fox, Howard, F.G.S. Rosehill, Falmouth.
1847. *Fox, Joseph Hoyland. The Clive, Wellington, Somerset.
1900. *Fox, Thomas. Old Way House, Wellington, Somerset.
1909. *Fox, Wilson Lloyd. Carmino, Falmouth.
1908. §Foxley, Miss Barbara, M.A. 12 Lime-grove, Manchester.
1881. *FOXWELL, HERBERT S., M.A., F.S.S. (Council, 1894-97), Professor of Political Economy in University College, London. St. John's College, Cambridge.
1907. §Fraine, Miss Ethel de, D.Sc., F.L.S. 223 Shrewsbury-road, Forest Gate, E.
1905. ‡Frames, Henry J. Talana, St. Patrick's-avenue, Parktown, Johannesburg.
1905. ‡Frames, Mrs. Talana, St. Patrick's-avenue, Parktown, Johannesburg.
1905. ‡Francke, M. P.O. Box 1156, Johannesburg.
1887. *FRANKLAND, PERCY F., Ph.D., B.Sc., F.R.S. (Pres. B, 1901), Professor of Chemistry in the University of Birmingham.
1910. *FRANKLIN, GEORGE, Litt.D. Tapton Hall, Sheffield.
1911. §FRASER, Dr. A. MEARNS. (LOCAL SECRETARY, 1911.) Town Hall, Portsmouth.
1895. ‡Fraser, Alexander. 63 Church-street, Inverness.
1885. ‡FRASER, ANGUS, M.A., M.D., F.C.S. (Local Sec. 1885.) 232 Union-street, Aberdeen.
1906. *FRASER, Miss HELEN C. I., D.Sc., F.L.S., Department of Botany, Birkbeck College, London. 27 Lincoln's Inn-fields, W.C.
1871. ‡FRASER, Sir THOMAS R., M.D., F.R.S., F.R.S.E., Professor of Materia Medica and Clinical Medicine in the University of Edinburgh. 13 Drumsheugh-gardens, Edinburgh.
1884. *FREMANTLE, The Hon. Sir C. W., K.C.B. (Pres. F, 1892; Council, 1897-1903.) 4 Lower Sloane-street, S.W.
1906. §French, Fleet-Surgeon A. M. Langley, Beaufort-road, Kingston-on-Thames.

Year of Election.

1909. §French, Mrs. Harriet A. Suite E, Gline's-block, Portage-avenue, Winnipeg, Canada.
1905. ‡French, Sir Somerset R., K.C.M.G. 100 Victoria-street, S.W.
1886. ‡FRESHFIELD, DOUGLAS W., F.R.G.S. (Pres. E, 1904.) 1 Airlie-gardens, Campden Hill, W.
1901. ‡Frew, William, Ph.D. King James-place, Perth.
1887. *Fries, Harold H., Ph.D. 92 Reade-street, New York, U.S.A.
1906. §Fritsch, Dr. F. E. 77 Chatsworth-road, Brondesbury, N.W.
1892. *Frost, Edmund, M.D. Chesterfield-road, Eastbourne.
1882. §Frost, Edward P., J.P. West Wratting Hall, Cambridgeshire.
1887. *Frost, Robert, B.Sc. 55 Kensington-court, W.
1898. ‡FRY, The Right Hon. Sir EDWARD, G.C.B., D.C.L., LL.D., F.R.S., F.S.A. Failand House, Failand, near Bristol.
1905. ‡Fry, H. P.O. Box 46, Johannesburg.
1875. *Fry, Joseph Storrs. 16 Upper Belgrave-road, Clifton, Bristol.
1908. ‡Fry, M. W. J., M.A. 39 Trinity College, Dublin.
1905. *Fry, William, J.P., F.R.G.S. Wilton House, Merrion-road, Dublin.
1898. ‡Fryer, Alfred C., Ph.D. 13 Eaton-crescent, Clifton, Bristol.
1872. *Fuller, Rev. A. 7 Sydenham-hill, Sydenham, S.E.
1869. ‡FULLER, G., M.Inst.C.E. (Local Sec. 1874.) 71 Lexham-gardens, Kensington, W.

1910. §Gadow, H. F., Ph.D., F.R.S. Zoological Laboratory, Cambridge.
1863. *Gainsford, W. D. Skendleby Hall, Spilsby.
1906. §Gajjar, Professor T. K., M.A. Techno-Chemical Laboratory, near Girgaum Tram Terminus, Bombay.
1885. *Gallaway, Alexander. Dirgarve, Aberfeldy, N.B.
1875. ‡GALLOWAY, W. Cardiff.
1887. *Galloway, W. J. The Cottage, Seymour-grove, Old Trafford, Manchester.
1905. ‡Galpin, Ernest E. Bank of Africa, Queenstown, Cape Colony.
1860. *GALTON, Sir FRANCIS, M.A., D.C.L., D.Sc., F.R.S., F.R.G.S. (GEN. SEC. 1863–68; Pres. E, 1862, 1872; Pres. H, 1885; Council, 1860–63.) 42 Rutland-gate, Knightsbridge, S.W.
1888. *GAMBLE, J. SYKES, C.I.E., M.A., F.R.S., F.L.S. Highfield, East Liss, Hants.
1899. *Garcke, E. Ditton House, near Maidenhead.
1898. ‡Garde, Rev. C. L. Skenfrith Vicarage, near Monmouth.
1905. ‡Gardiner, J. H. 59 Wroughton-road, Balham, S.W.
1900. ‡GARDINER, J. STANLEY, M.A., F.R.S., Professor of Zoology and Comparative Anatomy in the University of Cambridge. Gonville and Caius College, Cambridge.
1887. ‡GARDINER, WALTER, M.A., D.Sc., F.R.S. St. Awdreys, Hills-road, Cambridge.
1882. *Gardner, H. Dent, F.R.G.S. Fairmead, 46 The Goffs, Eastbourne.
1905. ‡Garlick, John. Thornibrae, Green Point, Cape Town.
1905. ‡Garlick, R. C. Thornibrae, Green Point, Cape Town.
1887. *Garnett, Jeremiah. The Grange, Bromley Cross, near Bolton, Lancashire.
1882. ‡Garnett, William, D.C.L. London County Council, Victoria Embankment, W.C.
1883. ‡GARSON, J. G., M.D. (ASSIST. GEN. SEC. 1902–04.) Moorcote, Eversley, Winchfield.
1903. ‡Garstang, A. H. 20 Roe-lane, Southport.
1903. *Garstang, T. James, M.A. Bedale's School, Petersfield, Hampshire.

Year of Election.

1894. *GARSTANG, WALTER, M.A., D.Sc., F.Z.S., Professor of Zoology in the University of Leeds.
1874. *Garstin, John Ribton, M.A., LL.B., M.R.I.A., F.S.A. Bragans-town, Castlebellingham, Ireland.
1905. ‡Garthwaite, E. H. B. S. A. Co., Bulawayo, South Africa.
1889. ‡GARWOOD, Professor E. J., M.A., F.G.S. University College, Gower-street, W.C.
1905. ‡Gaskell, Miss C. J. The Uplands, Great Shelford, Cambridge.
1905. ‡Gaskell, Miss M. A. The Uplands, Great Shelford, Cambridge.
1896. *GASKELL, WALTER HOLBROOK, M.A., M.D., LL.D., F.R.S. (Pres. I, 1896; Council, 1898-1901.) The Uplands, Great Shelford, Cambridge.
1906. §Gaster, Lèon. 32 Victoria-street, S.W.
1905. ‡Gaughren, Right Rev. Dr. M. Dutoitspan-road, Kimberley.
1905. *Gearon, Miss Susan. 55 Buckleigh-road, Streatham Common, S.W.
1867. ‡GEIKIE, Sir ARCHIBALD, K.C.B., LL.D., D.Sc., Pres.R.S., F.R.S.E., F.G.S. (PRESIDENT, 1892; Pres. C, 1867, 1871, 1899; Council, 1888-1891.) Shepherd's Down, Haslemere, Surrey.
1871. ‡GEIKIE, JAMES, LL.D., D.C.L., F.R.S., F.R.S.E., F.G.S. (Pres. C, 1889; Pres. E, 1892), Murchison Professor of Geology and Mineralogy in the University of Edinburgh. Kilmorie, Colinton-road, Edinburgh.
1898. ‡Gemmill, James F., M.A., M.D. 21 Endsleigh-gardens, Partick-hill, Glasgow.
1882. *GENESE, R. W., M.A., Professor of Mathematics in University College, Aberystwyth.
1905. ‡Gentleman, Miss A. A. 9 Abercromby-place, Stirling.
1902. *Gepp, Antony, M.A., F.L.S. British Museum (Natural History), Cromwell-road, S.W.
1899. *Gepp, Mrs. A. 7 Cumberland-road, Kew.
1884. *Gerrans, Henry T., M.A. 20 St. John-street, Oxford.
1909. §GIBBONS, W. M., M.A. (Local Sec. 1910.) The University, Sheffield.
1905. §Gibbs, Miss Lilian S., F.L.S. 22 South-street, Thurloe-square, S.W.
1902. ‡Gibson, Andrew. 14 Cliftonville-avenue, Belfast.
1901. §Gibson, Professor George A., M.A. 10 The University, Glasgow.
1876. *Gibson, George Alexander, M.D., D.Sc., LL.D., F.R.S.E. 3 Drumsheugh-gardens, Edinburgh.
1904. *Gibson, Mrs. Margaret D., LL.D. Castle Brae, Chesterton-lane, Cambridge.
1896. ‡GIBSON, R. J. HARVEY, M.A., F.R.S.E., Professor of Botany in the University of Liverpool.
1889. *Gibson, T. G. Lesbury House, Lesbury, R.S.O., Northumberland.
1893. ‡Gibson, Walcot, F.G.S. 28 Jermyn-street, S.W.
1898. *Gifford, J. William. Oaklands, Chard.
1883. §Gilbert, Lady. Park View, Englefield Green, Surrey.
1884. *Gilbert, Philip H. 63 Tupper-street, Montreal, Canada.
1895. ‡GILCHRIST, J. D. F., M.A., Ph.D., B.Sc., F.L.S. Marine Biologist's Office, Department of Agriculture, Cape Town.
1896. *GILCHRIST, PERCY C., F.R.S., M.Inst.C.E. Reform Club, Pall Mall, S.W.
1878. ‡Giles, Oliver. Brynteg, The Crescent, Bromsgrove.
1871. *GILL, Sir DAVID, K.C.B., LL.D., D.Sc., F.R.S., Hon.F.R.S.E. (PRESIDENT, 1907.) 34 De Vere-gardens, Kensington, W.
1902. ‡Gill, James F. 72 Strand-road, Bootle, Liverpool.

Year of Election.

1908. ‡Gill, T. P. Department of Agriculture and Technical Instruction for Ireland, Dublin.
1892. *Gilmour, Matthew A. B., F.Z.S. Saffronhall House, Windmill-road, Hamilton, N.B.
1907. ‡Gilmour, S. C. 25 Cumberland-road, Acton, W.
1908. ‡Gilmour, T. L. 1 St. John's Wood Park, N.W.
1893. *Gimingham, Edward. Croyland, Clapton Common, N.
1904. ‡Ginn, S. R., D.L. (Local Sec. 1904.) Brookfield, Trumpington-road, Cambridge.
1884. ‡Girdwood, G. P., M.D. 28 Beaver Hall-terrace, Montreal, Canada.
1886. *Gisborne, Hartley, M.Can.S.C.E. Yoxall, Ladysmith, Vancouver Island, Canada.
1883. *Gladstone, Miss. 19 Chepstow-villas, Bayswater, W.
1871. *Glaisher, J. W. L., M.A., D.Sc., F.R.S., F.R.A.S. (Pres. A, 1890; Council, 1878-86.) Trinity College, Cambridge.
1880. *Glantawe, Right Hon. Lord. The Grange, Swansea.
1881. *Glazebrook, R. T., C.B., M.A., D.Sc., F.R.S. (Pres. A, 1893; Council 1890-94, 1905-), Director of the National Physical Laboratory. Bushy House, Teddington, Middlesex.
1881. *Gleadow, Frederic. 38 Ladbroke-grove, W.
Glover, Thomas. 124 Manchester-road, Southport.
1878. *Godlee, J. Lister. Wakes Colne Place, Essex.
1880. ‡Godman, F. Du Cane, D.C.L., F.R.S., F.L.S., F.G.S. 10 Chandos-street, Cavendish-square, W.
1879. ‡Godwin-Austen, Lieut.-Colonel H. H., F.R.S., F.R.G.S., F.Z.S. (Pres. E, 1883.) Nore, Godalming.
1878. ‡Goff, James. (Local Sec. 1878.) 29 Lower Leeson-street, Dublin.
1908. *Gold, Ernest, M.A. 3 Devana-terrace, Cambridge.
1906. ‡Goldie, Right Hon. Sir George D. T., K.C.M.G., D.C.L., F.R.S. (Pres. E, 1906; Council, 1906-07.) 44 Rutland-gate, S.W.
1910. §Golding, John, F.I.C. Midland Agricultural and Dairy College, Kingston, near Derby.
1898. ‡Goldney, F. Bennett, F.S.A. Goodnestone Park, Dover.
1899. ‡Gomme, Sir G. L., F.S.A. 24 Dorset-square, N.W.
1890. *Gonner, E. C. K., M.A. (Pres. F, 1897), Professor of Political Economy in the University of Liverpool.
1909. ‡Goodair, Thomas. 303 Kennedy-street, Winnipeg, Canada.
1907. §Goodrich, E. S., M.A., F.R.S., F.L.S. Merton College, Oxford.
1884. *Goodridge, Richard E. W. Coleraine, Minnesota, U.S.A.
1884. ‡Goodwin, Professor W. L. Queen's University, Kingston, Ontario, Canada.
1905. ‡Goold-Adams, Major Sir H. J., G.C.M.G., C.B. Government House, Bloemfontein, South Africa.
1909. §Gordon, Rev. Charles W. 567 Broadway, Winnipeg, Canada.
1909. ‡Gordon, J. T. 147 Hargrave-street, Winnipeg, Canada.
1909. ‡Gordon, Mrs. J. T. 147 Hargrave-street, Winnipeg, Canada.
1871. *Gordon, Joseph Gordon, F.C.S. Queen Anne's-mansions, Westminster, S.W.
1893. ‡Gordon, Mrs. M. M. Ogilvie, D.Sc. 1 Rubislaw-terrace, Aberdeen.
1910. *Gordon, Vivian. Avonside Engine Works, Fishponds, Bristol.
1901. ‡Gorst, Right Hon. Sir John E., M.A., K.C., M.P., F.R.S. (Pres. L, 1901.) 21 Victoria-square, S.W.
1875. *Gotch, Francis, M.A., D.Sc., F.R.S. (Pres. I, 1906; Council, 1901-07), Professor of Physiology in the University of Oxford. The Lawn, Banbury-road, Oxford.
1881. ‡Gough, Rev. Thomas, B.Sc. King Edward's School, Retford.

Year of Election.

1901. ‡GOURLAY, ROBERT. Glasgow.
1901. ‡Gow, Leonard. Hayston, Kelvinside, Glasgow.
1876. ‡Gow, Robert. Cairndowan, Dowanhill-gardens, Glasgow.
1883. ‡Gow, Mrs. Cairndowan, Dowanhill-gardens, Glasgow.
1873. ‡Goyder, Dr. D. Marley House, 88 Great Horton-road, Bradford, Yorkshire.
1908. §Grabham, G. W., M.A., F.G.S. P.O. Box 178, Khartoum, Sudan.
1886. ‡Grabham, Michael C., M.D. Madeira.
1909. ‡Grace, J. H., M.A., F.R.S. Peterhouse, Cambridge.
1909. ‡Graham, Herbert W. 329 Kennedy-street, Winnipeg, Canada.
1902. *Graham, William, M.D. District Lunatic Asylum, Belfast.
1875. ‡GRAHAME, JAMES. (Local Sec. 1876.) Care of Messrs. Grahame, Crums, & Connal, 34 West George-street, Glasgow.
1904. §Gramont, Comte Arnaud de, D.Sc. 179 rue de l'Université, Paris.
1896. ‡Grant, Sir James, K.C.M.G. Ottawa, Canada.
1908. *Grant, W. L. 10 Park-terrace, Oxford.
1905. ‡Graumann, Harry. P.O. Box 2115, Johannesburg.
1890. ‡GRAY, ANDREW, M.A., LL.D., F.R.S., F.R.S.E., Professor of Natural Philosophy in the University of Glasgow.
1905. ‡Gray, C. J. P.O. Box 208, Pietermaritzburg, South Africa.
1864. *Gray, Rev. Canon Charles. West Retford Rectory, Retford.
1881. ‡Gray, Edwin, LL.B. Minster-yard, York.
1903. §Gray, Ernest, M.A. 99 Grosvenor-road, S.W.
1904. ‡GRAY, Rev. H. B., D.D. (Pres. L, 1909.) The College, Bradfield, Berkshire.
1892. *Gray, James Hunter, M.A., B.Sc. 3 Crown Office-row, Temple, E.C.
1904. ‡*Gray, J. Marfarlane. 4 Ladbroke-crescent, W.*
1892. §GRAY, JOHN, B.Sc. 9 Park-hill, Clapham Park, S.W.
1887. ‡Gray, Joseph W., F.G.S. St. Elmo, Leckhampton-road, Cheltenham.
1887. ‡Gray, M. H., F.G.S. Lessness Park, Abbey Wood, Kent.
1886. *Gray, Robert Kaye. Lessness Park, Abbey Wood, Kent.
1901. ‡Gray, R. W. University College, W.C.
1873. ‡Gray, William, M.R.I.A. Glenburn Park, Belfast.
*GRAY, Colonel WILLIAM. Farley Hall, near Reading.
1866. §Greaves, Charles Augustus, M.B., LL.B. 84 Friar-gate, Derby.
1893. *Greaves, Mrs. Elizabeth. Station-street, Nottingham.
1910. §Greaves, R. H., B.Sc. 12 St. John's-crescent, Cardiff.
1905. ‡Green, A. F. Sea Point, Cape Colony.
1904. *Green, Professor A. G., M.Sc. The Old Gardens, Cardigan-road, Headingley, Leeds.
1904. §Green, F. W. 5 Wordsworth-grove, Cambridge.
1906. §Green, J. A., M.A., Professor of Education in the University of Sheffield.
1888. §GREEN, J. REYNOLDS, M.A., D.Sc., F.R.S., F.L.S. (Pres. K, 1902.) Downing College, Cambridge.
1903. ‡Green, W. J. 76 Alexandra-road, N.W.
1908. ‡Green, Rev. William Spotswood, C.B., F.R.G.S. 5 Cowper-villas, Cowper-road, Dublin.
1909. ‡Greenfield, Joseph. P.O. Box 2935, Winnipeg, Canada.
1882. ‡GREENHILL, Sir A. G., M.A., F.R.S. 1 Staple Inn, W.C.
1905. ‡Greenhill, Henry H. P.O. Box 172, Bloemfontein, South Africa.
1905. ‡Greenhill, William. 6A George-street, Edinburgh.
1898. *GREENLY, EDWARD, F.G.S. Achnashean, near Bangor, North Wales.

Year of Election.

1875. §Greenwood, Dr. Frederick. Brampton, Chesterfield.
1906. ‡Greenwood, Hamar. National Liberal Club, Whitehall-place, S.W.
1894. *GREGORY, J. WALTER, D.Sc., F.R.S., F.G.S. (Pres. C, 1907), Professor of Geology in the University of Glasgow.
1896. *GREGORY, Professor R. A., F.R.A.S. Dell Quay House, near Chichester.
1904. *Gregory, R. P., M.A. 156 Chesterton-road, Cambridge.
1881. ‡Gregson, William, F.G.S. 106 Victoria-road, Darlington.
1836. Griffin, S. F. Albion Tin Works, York-road, N.
1894. *Griffith, C. L. T., Assoc.M.Inst.C.E. Municipal Offices, Madras.
1908. §Griffith, John P. Rathmines Castle, Rathmines, Dublin.
1884. ‡GRIFFITHS, E. H., M.A., D.Sc., F.R.S. (Pres. A, 1906), Principal of University College, Cardiff.
1884. ‡Griffiths, Mrs. University College, Cardiff.
1847. ‡Griffiths, Thomas. The Elms, Harborne-road, Edgbaston, Birmingham.
1903. ‡Griffiths, Thomas, J.P. 101 Manchester-road, Southport.
1888. *Grimshaw, James Walter, M.Inst.C.E. St. Stephen's Club, Westminster, S.W.
1894. ‡GROOM, Professor P., M.A., F.L.S. Hollywood, Egham, Surrey.
1894. ‡Groom, T. T., M.A., D.Sc., F.G.S., Professor of Geology in the University of Birmingham.
1909. *Grossman, Edward L., M.D. Steilacoom, Washington, U.S.A.
1896. ‡Grossmann, Dr. Karl. 70 Rodney-street, Liverpool.
1904. ‡Grosvenor, G. H. New College, Oxford.
1869. ‡GRUBB, Sir HOWARD, F.R.S., F.R.A.S. Rockdale, Orwell-road, Rathgar, Dublin.
1897. ‡Grünbaum, A. S., M.A., M.D. School of Medicine, Leeds.
1910. §Grundy, James. 8 Grosvenor-gardens, Cricklewood, N.W.
1887. ‡GUILLEMARD, F. H. H., M.A., M.D. The Mill House, Trumpington, Cambridge.
1905. *Gunn, Donald. Royal Societies Club, St. James's-street, S.W.
1909. ‡Gunne, J. R., M.D. Kenora, Ontario, Canada.
1909. ‡Gunne, W. J., M.D. Kenora, Ontario, Canada.
1866. ‡GÜNTHER, ALBERT C. L. G., M.A., M.D., Ph.D., F.R.S., F.L.S., F.Z.S. (Pres. D, 1880.) 22 Lichfield-road, Kew, Surrey.
1894. ‡Günther, R. T. Magdalen College, Oxford.
1880. §Guppy, John J. Ivy-place, High-street, Swansea.
1904. §Gurney, Eustace. Sprowston Hall, Norwich.
1902. *Gurney, Robert. Ingham Old Hall, Stalham, Norfolk.
1904. ‡Guttmann, Professor Leo F., Ph.D. Queen's University, Kingston, Canada.

1905. ‡Hacker, Rev. W. J. Edendale, Pietermaritzburg, South Africa.
1908. *Hackett, Felix E. Royal College of Science, Dublin.
1881. *HADDON, ALFRED CORT, M.A., D.Sc., F.R.S., F.Z.S. (Pres. H, 1902, 1905; Council, 1902–08, 1910– .) Inisfail, Hills-road, Cambridge.
1905. ‡Haddon, Miss. Inisfail, Hills-road, Cambridge.
1888. *Hadfield, Sir R. A., F.R.S., M.Inst.C.E. Parkhead House, Sheffield.
1905. ‡Hahn, Professor P. D., M.A., Ph.D. York House, Gardens, Cape Town.
1906. ‡Hake, George W. Oxford, Ohio, U.S.A.
1894. ‡HALDANE, JOHN SCOTT, M.A., M.D., F.R.S. (Pres. I, 1908), Reader in Physiology in the University of Oxford. Cherwell, Oxford.

Year of Election.

1909. §Hale, W. H., Ph.D. 40 First-place, Brooklyn, New York, U.S.A.
1899. ‡HALL, A. D., M.A., F.R.S. (Council, 1908–), Director of the Rothamsted Experimental Station, Harpenden, Herts.
1909. §Hall, Archibald A., M.Sc., Ph.D. Armstrong College, Newcastle-on-Tyne.
1903. ‡HALL, E. MARSHALL, K.C. 75 Cambridge-terrace, W.
1879. *Hall, Ebenezer. Abbeydale Park, near Sheffield.
1883. *Hall, Miss Emily. 63 Belmont-street, Southport.
1854. *HALL, HUGH FERGIE, F.G.S. Cissbury Court, West Worthing, Sussex.
1899. ‡Hall, John, M.D. National Bank of Scotland, 37 Nicholas-lane, E.C.
1884. §Hall, Thomas Proctor, M.D. 1301 Davie-street, Vancouver, B.C., Canada.
1908. *Hall, Wilfred, Assoc.M.Inst.C.E. 9 Prior's-terrace, Tynemouth, Northumberland.
1891. *Hallett, George. Cranford, Victoria-square, Penarth.
1873. *HALLETT, T. G. P., M.A. Claverton Lodge, Bath.
1888. §HALLIBURTON, W. D., M.D., LL.D., F.R.S. (Pres. I, 1902; Council, 1897–1903), Professor of Physiology in King's College, London Church Cottage, 17 Marylebone-road, N.W.
1905. ‡Halliburton, Mrs. Church Cottage, 17 Marylebone-road, N.W.
1904. *Hallidie, A. H. S. Avondale, Chesterfield-road, Eastbourne.
1908. ‡Hallitt, Mrs. Steeple Grange, Wirksworth.
1908. *Hamel, Egbert Alexander de. Middleton Hall, Tamworth.
1883. *Hamel, Egbert D. de. Middleton Hall, Tamworth.
1904. *Hamel de Manin, Anna Countess de. 35 Circus-road, N.W.
1906. ‡Hamill, John Molyneux, M.A., M.B. 14 South-parade, Chiswick.
1906. ‡Hamilton, Charles I. 88 Twyford-avenue, Acton.
1909. ‡Hamilton, F. C. Bank of Hamilton-chambers, Winnipeg, Canada.
1902. ‡HAMILTON, Rev. T., D.D. Queen's College, Belfast.
1909. ‡Hamilton, T. Glen, M.D. 264 Renton-avenue, Winnipeg, Canada.
1905. ‡Hammersley-Heenan, R. H., M.Inst.C.E. Harbour Board Offices, Cape Town.
1905. ‡Hammond, Miss Edith. High Dene, Woldingham, Surrey.
1881. *HAMMOND, ROBERT, M.Inst.C.E. 64 Victoria-street, Westminster, S.W.
1899. *Hanbury, Daniel. Lenqua da Cà, Alassio, Italy.
1878. ‡Hance, E. M. Care of J. Hope Smith, Esq., 3 Leman-street, E.C.
1909. §Hancock, C. B. Manitoba Government Telephones, Winnipeg, Canada.
1905. *Hancock, Strangman. Kennel Holt, Cranbrook, Kent.
1890. ‡*Hankin, Ernest Hanbury. St. John's College, Cambridge.*
1906. §Hanson, David. Salterlee, Halifax, Yorkshire.
1904. §Hanson, E. K. 2 The Parade, High-street, Watford; and Woodthorpe, Royston Park-road, Hatch End, Middlesex.
1859. *HARCOURT, A. G. VERNON, M.A., D.C.L., LL.D., D.Sc., F.R.S., V.P.C.S. (GEN. SEC. 1883–97; Pres. B, 1875; Council, 1881–83.) St. Clare, Ryde, Isle of Wight.
1909. §Harcourt, George. Department of Agriculture, Edmonton, Alta., Canada.
1886. *Hardcastle, Colonel Basil W., F.S.S. 12 Gainsborough-gardens, Hampstead, N.W.
1902. **HARDCASTLE, Miss FRANCES. 25 Boundary-road, N.W.*
1903. *Hardcastle, J. Alfred. The Dial House, Crowthorne, Berkshire.
1892. *HARDEN, ARTHUR, Ph.D., D.Sc., F.R.S. Lister Institute of Preventive Medicine, Chelsea-gardens, Grosvenor-road, S.W.

Year of
Election.

1905. ‡Hardie, Miss Mabel, M.B. High-lane, *viâ* Stockport.
1877. ‡Harding, Stephen. Bower Ashton, Clifton, Bristol.
1894. ‡Hardman, S. C. 120 Lord-street, Southport.
1909. §Hardy, W. B., M.A., F.R.S. Gonville and Caius College, Cambridge.
1881. ‡Hargrove, William Wallace. St. Mary's, Bootham, York.
1890. *HARKER, ALFRED, M.A., F.R.S., F.G.S. St. John's College, Cambridge.
1896. ‡Harker, John Allen, D.Sc., F.R.S. National Physical Laboratory, Bushy House, Teddington.
1875. *Harland, Rev. Albert Augustus, M.A., F.G.S., F.L.S., F.S.A. The Vicarage, Harefield, Middlesex.
1905. ‡Harland, H. C. P.O. Box 1024, Johannesburg.
1877. *Harland, Henry Seaton. 8 Arundel-terrace, Brighton.
1883. *Harley, Miss Clara. Rosslyn, Westbourne-road, Forest-hill, S.E.
1868. *HARMER, F. W., F.G.S. Oakland House, Cringleford, Norwich.
1881. *HARMER, SIDNEY F., M.A., Sc.D., F.R.S. (Pres. D, 1908.) Keeper of the Department of Zoology, British Museum (Natural History), Cromwell-road, S.W.
1906. ‡Harper, J. B. 16 St. George's-place, York.
1842. *Harris, G. W. Millicent, South Australia.
1909. ‡Harris, J. W. Civic Offices, Winnipeg.
1903. ‡Harris, Robert, M.B. Queen's-road, Southport.
1904. *Harrison, Frank L., B.A. The Grammar School, Soham, Cambridgeshire.
1904. ‡Harrison, H. Spencer. The Horniman Museum, Forest-hill, S.E.
1892. ‡HARRISON, JOHN. (Local Sec. 1892.) Rockville, Napier-road, Edinburgh.
1870. ‡HARRISON, REGINALD, F.R.C.S. (Local Sec. 1870.) 6 Lower Berkeley-street, Portman-square, W.
1892. ‡Harrison, Rev. S. N. Ramsey, Isle of Man.
1901. *Harrison, W. E. 17 Soho-road, Handsworth, Staffordshire.
1885. ‡HART, Colonel C. J. (Local Sec. 1886.) Highfield Gate, Edgbaston, Birmingham.
1909. ‡Hart, John A. 120 Emily-street, Winnipeg, Canada.
1876. *Hart, Thomas. Brooklands, Blackburn.
1903. *Hart, Thomas Clifford. Brooklands, Blackburn.
1907. §Hart, W. E. Kilderry, near Londonderry.
1893. *HARTLAND, E. SIDNEY, F.S.A. (Pres. H, 1906; Council, 1906– .) Highgarth, Gloucester.
1905. ‡Hartland, Miss. Highgarth, Gloucester.
1871. *HARTLEY, WALTER NOEL, D.Sc., F.R.S., F.R.S.E., F.C.S. (Pres. B, 1903), Professor of Chemistry in the Royal College of Science, Dublin. 10 Elgin-road, Dublin.
1886. *HARTOG, Professor M. M., D.Sc. University College, Cork.
1887. ‡HARTOG, P. J., B.Sc. University of London, South Kensington, S.W.
1905. ‡Harvey-Hogan, J. P.O. Box 1277, Johannesburg.
1885. §Harvie-Brown, J. A. Dunipace, Larbert, N.B.
1862. *Harwood, John. Woodside Mills, Bolton-le-Moors.
1893. §Haslam, Lewis. 44 Evelyn-gardens, S.W.
1903. *Hastie, Miss J. A. Care of Messrs. Street & Co., 30 Cornhill, E.C.
1903. ‡Hastie, William. 20 Elswick-row, Newcastle-on-Tyne.
1904. ‡HASTINGS, G. 15 Oak-lane, Bradford, Yorkshire.
1875. *HASTINGS, G. W. (Pres. F, 1880.) Chapel House, Chipping Norton.
1903. ‡Hastings, W. G. W. 2 Halsey-street, Cadogan-gardens, S.W.

Year of Election.

1889. ‡HATCH, F. H., Ph.D., F.G.S. Southacre, Trumpington-road, Cambridge.
1903. ‡Hathaway, Herbert G. 45 High-street, Bridgnorth, Salop.
1904. *Haughton, W. T. H. The Highlands, Great Barford, St. Neots.
1908. §Havelock, T. H. Rockliffe, Gosforth, Newcastle-on-Tyne.
1904. ‡Havilland, Hugh de. Eton College, Windsor.
1887. *Hawkins, William. Earlston House, Broughton Park, Manchester.
1872. *Hawkshaw, Henry Paul. 58 Jermyn-street, St. James's, S.W.
1864. *HAWKSHAW, JOHN CLARKE, M.A., M.Inst.C.E., F.G.S. (Council, 1881–87.) 22 Down-street, W., and 33 Great George-street, S.W.
1897. §HAWKSLEY, CHARLES, M.Inst.C.E., F.G.S. (Pres. G, 1903; Council, 1902–09.) Caxton House (West Block), Westminster, S.W.
1887. *Haworth, Jesse. Woodside, Bowdon, Cheshire.
1861. *HAY, Admiral the Right Hon. Sir JOHN C. D., Bart., G.C.B., D.C.L., F.R.S. 108 St. George's-square, S.W.
1885. *HAYCRAFT, JOHN BERRY, M.D., B.Sc., F.R.S.E., Professor of Physiology in University College, Cardiff.
1900. §Hayden, H. H., B.A., F.G.S. Geological Survey, Calcutta, India.
1903. *Haydock, Arthur. 155 Leamington-road, Blackburn.
1903. ‡Hayward, Joseph William, M.Sc. Keldon, St. Marychurch, Torquay.
1896. *Haywood, Colonel A. G. Rearsby, Merrilocks-road, Blundellsands.
1879. *Hazelhurst, George S. The Grange, Rockferry.
1909. ‡Heaman, J. A., B.Sc. Suite 20, Moxam-court, Winnipeg, Canada.
1883. ‡Heape, Joseph R. Glebe House, Rochdale.
1882. *Heape, Walter, M.A., F.R.S. Greyfriars, Southwold, Suffolk.
1909. ‡Heard, Mrs. Sophie, M.B., Ch.B. Care of Major R. Heard, Lower Mall, Lahore, India.
1908. §Heath, J. St. George, B.A. Woodbrooke Settlement, Selly Oak, near Birmingham.
1902. ‡Heath, J. W. Royal Institution, Albemarle-street, W.
1909. ‡Heathcote, F. C. C. Broadway, Winnipeg, Canada.
1902. ‡Heathorn, Captain T. B., R.A. 10 Wilton-place, Knightsbridge, S.W.
1883. ‡Heaton, Charles. Marlborough House, Hesketh Park, Southport.
1892. *HEATON, WILLIAM H., M.A. (Local Sec. 1893), Professor of Physics in University College, Nottingham.
1889. *Heaviside, Arthur West, I.S.O. 12 Tring-avenue, Ealing, W.
1888. *Heawood, Edward, M.A. Briarfield, Church-hill, Merstham, Surrey.
1888. *Heawood, Percy J., Lecturer in Mathematics in Durham University. 41 Old Elvet, Durham.
1887. *HEDGES, KILLINGWORTH, M.Inst.C.E. 10 Cranley-place, South Kensington, S.W.
1881. *HELE-SHAW, H. S., LL.D., F.R.S., M.Inst.C.E. 64 Victoria-street, S.W.
1901. *HELLER, W. M., B.Sc. 40 Upper Sackville-street, Dublin.
1905. ‡Hellman, Hugo. Rand Club, Johannesburg.
1887. §Hembry, Frederick William, F.R.M.S. Langford, Sidcup, Kent.
1899. ‡Hemsalech, G. A., D.Sc. The Owens College, Manchester.
1905. *Henderson, Andrew. 17 Belhaven-terrace, Glasgow.
1905. *Henderson, Miss Catharine. 17 Belhaven-terrace, Glasgow.
1891. *HENDERSON, G. G., D.Sc., M.A., F.I.C., Professor of Chemistry in the Glasgow and West of Scotland Technical College, Glasgow.
1905. §Henderson, Mrs. Technical College, Glasgow.
1907. §Henderson, H. F. Felday, Morland-avenue, Leicester.

Year of Election.

1906. ‡Henderson, J. B., D.Sc., Professor of Applied Mechanics in the Royal Naval College, Greenwich, S.E.
1909. ‡Henderson, Veylien E. Medical Building, The University, Toronto Canada.
1909. ‡Henderson, W. G. Louise Bridge, Winnipeg, Canada.
1880. *Henderson, Vice-Admiral W. H., R.N. 12 Vicarage-gardens, Campden Hill, W.
1904. *Hendrick, James. Marischal College, Aberdeen.
1910. §Heney, T. W. Sydney, New South Wales.
1910. *Henrici, Captain E. O., R.E., A.Inst.C.E. Ordnance Survey Office, Southampton.
1873. *HENRICI, OLAUS M. F. E., Ph.D., F.R.S. (Pres. A, 1883; Council, 1883–89), Professor of Mechanics and Mathematics in the City and Guilds of London Institute, Central Institution, Exhibition-road, S.W. 34 Clarendon-road, Notting Hill, W.
1910. §Henry, Hubert, M.D. 304 Glossop-road, Sheffield.
1906. ‡Henry, Dr. T. A. Imperial Institute, S.W.
1909. *Henshall, Robert. Sunnyside, Latchford, Warrington.
1892. ‡HEPBURN, DAVID, M.D., F.R.S.E., Professor of Anatomy in University College, Cardiff.
1904. ‡Hepworth, Commander M. W. C., C.B., R.N.R. Meteorological Office, Victoria-street, S.W.
1892. *HERBERTSON, A. J., M.A., Ph.D. (Pres. E, 1910), Professor of Geography in the University of Oxford. 43 Banbury-road, Oxford.
1909. ‡Herbinson, William. 376 Ellice-avenue, Winnipeg, Canada.
1902. ‡Herdman, G. W., B.Sc., Assoc.M.Inst.C.E. Irrigation and Water Supply Department, Pretoria.
1887. *HERDMAN, WILLIAM A., D.Sc., F.R.S., F.R.S.E., F.L.S. (GENERAL SECRETARY, 1903– ; Pres. D, 1895; Council, 1894–1900; Local Sec. 1896), Professor of Natural History in the University of Liverpool. Croxteth Lodge, Sefton Park, Liverpool.
1893. *Herdman, Mrs. Croxteth Lodge, Sefton Park, Liverpool.
1909. ‡Herdt, Professor L. A. McGill University, Montreal, Canada.
1875. ‡HEREFORD, The Right Rev. JOHN PERCIVAL, D.D., LL.D., Lord Bishop of. (Pres. L, 1904.) The Palace, Hereford.
1908. *Herring, Dr. Percy T. The University, St. Andrews, N.B.
1874. §HERSCHEL, Colonel JOHN, R.E., F.R.S., F.R.A.S. Observatory House, Slough, Bucks.
1900. *Herschel, Rev. J. C. W. Fircroft, Wellington College Station, Berkshire.
1905. ‡Hervey, Miss Mary F. S. 22 Morpeth-mansions, S.W.
1903. *HESKETH, CHARLES H. FLEETWOOD, M.A. Stocken Hall, Stretton, Oakham.
1895. §Hesketh, James. 5 Scarisbrick Avenue, Southport.
1905. ‡Hewat, M. L., M.D. Mowbray, near Cape Town, South Africa.
1894. ‡HEWETSON, G. H. (Local Sec. 1896.) 39 Henley-road, Ipswich.
1894. ‡Hewins, W. A. S., M.A., F.S.S. 15 Chartfield-avenue, Putney Hill, S.W.
1908. ‡Hewitt, Dr. C. Gordon. Central Experimental Farm, Ottawa.
1896. §Hewitt, David Basil, M.D. Oakleigh, Northwich, Cheshire.
1903. ‡Hewitt, E. G. W. 87 Princess-road, Moss Side, Manchester.
1909. §Hewitt, F. W., M.V.O., M.D. 14 Queen Anne-street, W.
1903. ‡Hewitt, John Theodore, M.A., D.Sc., Ph.D., F.R.S. Clifford House, Staines-road, Bedfont, Middlesex.
1909. §Hewitt, W., B.Sc. 16 Clarence-road, Birkenhead.
1882. *HEYCOCK, CHARLES T., M.A., F.R.S. 3 St. Peter's-terrace, Cambridge.

Year of Election.

1883. ‡Heyes, Rev. John Frederick, M.A., F.R.G.S. St. Barnabas Vicarage, Bolton.
1866. *Heymann, Albert. West Bridgford, Nottinghamshire.
1901. *Heys, Z. John. Stonehouse, Barrhead, N.B.
1886. ‡HEYWOOD, HENRY, J.P. Witla Court, near Cardiff.
1898. ‡Hicks, Henry B. 44 Pembroke-road, Clifton, Bristol.
1877. §HICKS, W. M., M.A., D.Sc., F.R.S. (Vice-Pres. 1910; Pres. A, 1895), Professor of Physics in the University of Sheffield. Leamhurst, Ivy Park-road, Sheffield.
1886. ‡Hicks, Mrs. W. M. Leamhurst, Ivy Park-road, Sheffield.
1887. *HICKSON, SYDNEY J., M.A., D.Sc., F.R.S. (Pres. D, 1903), Professor of Zoology in Victoria University, Manchester.
1864. *HIERN, W. P., M.A., F.R.S. The Castle, Barnstaple.
1891. ‡HIGGS, HENRY, C.B., LL.B., F.S.S. (Pres. F, 1899; Council, 1904–06.) H.M. Treasury, Whitehall, S.W.
1909. ‡Higman, Ormond. Electrical Standards Laboratory, Ottawa.
1907. ‡HILEY, E. V. (Local Sec. 1907.) Town Hall, Birmingham.
1885. *HILL, ALEXANDER, M.A., M.D. Downing College, Cambridge.
1903. *HILL, ARTHUR W., M.A., F.L.S. Royal Gardens, Kew.
1906. §Hill, Charles A., M.A., M.B. 13 Rodney-street, Liverpool.
1881. *HILL, Rev. EDWIN, M.A. The Rectory, Cockfield, Bury St. Edmunds.
1908. *Hill, James P., D.Sc., Professor of Zoology in University College, Gower-street, W.C.
1886. ‡HILL, M. J. M., M.A., D.Sc., F.R.S., Professor of Pure Mathematics in University College, W.C.
1898. *Hill, Thomas Sidney. 143 Alexandra-road, St. John's Wood, N.W.
1907. *HILLS, Major E. H., C.M.G., R.E., F.R.G.S. (Pres. E, 1908.) 32 Prince's-gardens, S.W.
1903. *Hilton, Harold. 73 Platt's-lane, Hampstead, N.W.
1903. *HIND, WHEELTON, M.D., F.G.S. Roxeth House, Stoke-on-Trent.
1870. ‡HINDE, G. J., Ph.D., F.R.S., F.G.S. Ivythorn, Avondale-road, South Croydon, Surrey.
1910. §Hindle, Dr. Edward. Quick Laboratory, Cambridge.
1883. *Hindle, James Henry. 8 Cobham-street, Accrington.
1898. §Hinds, Henry. 57 Queen-street, Ramsgate.
1900. §Hinks, Arthur R., M.A. The Observatory, Cambridge.
1903. *Hinmers, Edward. Glentwood, South Downs-drive, Hale, Cheshire.
1899. ‡Hobday, Henry. Hazelwood, Crabble Hill, Dover.
1887. *Hobson, Bernard, M.Sc., F.G.S. Thornton, Hallam Gate-road, Sheffield.
1883. ‡Hobson, Mrs. Carey. 5 Beaumont-crescent, West Kensington, W.
1904. §HOBSON, ERNEST WILLIAM, Sc.D., F.R.S. (Pres. A, 1910), Sadlerian Professor of Pure Mathematics in the University of Cambridge. The Gables, Mount Pleasant, Cambridge.
1907. ‡Hobson, Mrs. Mary. 6 Hopefield-avenue, Belfast.
1877. ‡Hodge, Rev. John Mackey, M.A. 38 Tavistock-place, Plymouth.
1887. *Hodgkinson, Alexander, M.B., B.Sc., Lecturer on Laryngology in the Victoria University, Manchester. 18 St. John-street, Manchester.
1880. ‡Hodgkinson, W. R. Eaton, Ph.D., F.R.S.E., F.G.S., Professor of Chemistry and Physics in the Royal Artillery College, Woolwich. 18 Glenluce-road, Blackheath, S.E.
1905. ‡Hodgson, Ven. Archdeacon R. The Rectory, Wolverhampton.
1909. ‡Hodgson, R. T., M.A. Collegiate Institute, Brandon, Manitoba, Canada.

Year of Election.

1898. ‡Hodgson, T. V. Municipal Museum and Art Gallery, Plymouth.
1904. §Hodson, F. Bedale's School, Petersfield, Hampshire.
1904. ‡HOGARTH, D. G., M.A. (Pres. H, 1907; Council, 1907-10.) 20 St. Giles's, Oxford.
1894. ‡*Hogg, A. F., M.A. 13 Victoria-road, Darlington.*
1908. ‡Hogg, Right Hon. Jonathan. Stratford, Rathgar, Co. Dublin.
1907. ‡Holden, Colonel H. C. L., R.A., F.R.S. Gifford House, Blackheath, S.E.
1883. ‡Holden, John J. 73 Albert-road, Southport.
1887. *Holder, Henry William, M.A. Beechmount, Arnside.
1900. ‡HOLDICH, Colonel Sir THOMAS H., R.E., K.C.B., K.C.I.E., F.R.G.S. (Pres. E, 1902.) 41 Courtfield-road, S.W.
1887. *Holdsworth, C. J. Fernhill, Alderley Edge, Cheshire.
1904. §Holland, Charles E. 9 Downing-place, Cambridge.
1903. §Holland, J. L., B.A. 3 Primrose-hill, Northampton.
1896. ‡Holland, Mrs. Lowfields House, Hooton, Cheshire.
1898. ‡Holland, Sir Thomas H., K.C.I.E., F.R.S., F.G.S., Professor of Geology in the Victoria University, Manchester.
1889. ‡Holländer, Bernard, M.D. 35A Welbeck-street, W.
1906. *Hollingworth, Miss. Leithen, Newnham-road, Bedford.
1905. ‡Hollway, H. C. Schunke. Plaisir de Merle, P.O. Simondium, *viâ* Paarl, South Africa.
1883. *Holmes, Mrs. Basil. 23 Corfton-road, Ealing, Middlesex, W.
1866. *Holmes, Charles. 37 Margaret-street, W.
1882. *HOLMES, THOMAS VINCENT, F.G.S. 28 Croom's-hill, Greenwich, S.E.
1903. *HOLT, ALFRED, jun. Crofton, Aigburth, Liverpool.
1875. *Hood, John. Chesterton, Cirencester.
1904. §Hooke, Rev. D. Burford, D.D. Bonchurch Lodge, Barnet.
1847. ‡HOOKER, Sir JOSEPH DALTON, G.C.S.I., C.B., M.D., D.C.L., LL.D., F.R.S., F.L.S., F.G.S., F.R.G.S. (PRESIDENT, 1868; Pres. E, 1881; Council, 1866-67.) The Camp, Sunningdale, Berkshire.
1892. ‡HOOKER, REGINALD H., M.A. 3 Clement's Inn, W.C.
1908. *Hooper, Frank Henry. Clare College, Cambridge.
1865. *Hooper, John P. Deepdene, Streatham Common, S.W.
1877. *Hooper, Rev. Samuel F., M.A. Lydlinch Rectory, Sturminster Newton, Dorset.
1904. ‡Hopewell-Smith, A., M.R.C.S. 37 Park-street, Grosvenor-square, S.W.
1905. *Hopkins, Charles Hadley. Junior Constitutional Club, 101 Piccadilly, W.
1901. *Hopkinson, Bertram, M.A., F.R.S., F.R.S.E., Professor of Mechanism and Applied Mechanics in the University of Cambridge. Adams-road, Cambridge.
1884. *HOPKINSON, CHARLES. (Local Sec. 1887.) The Limes, Didsbury, near Manchester.
1882. *Hopkinson, Edward, M.A., D.Sc. Ferns, Alderley Edge, Cheshire.
1871. *HOPKINSON, JOHN, Assoc.Inst.C.E., F.L.S., F.G.S., F.R.Met.Soc. 84 New Bond-street, W.; and Weetwood, Watford.
1905. ‡Hopkinson, Mrs. John. Holmwood, Wimbledon Common, S.W.
1898. *Hornby, R., M.A. Haileybury College, Hertford.
1910. §Horne, Arthur S. 48 Highbury, Newcastle-on-Tyne.
1885. ‡HORNE, JOHN, LL.D., F.R.S., F.R.S.E., F.G.S. (Pres. C, 1901.) Geological Survey Office, Sheriff Court-buildings, Edinburgh.
1903. ‡Horne, William, F.G.S. Leyburn, Yorkshire.
1902. ‡Horner, John. Chelsea, Antrim-road, Belfast.
1905. *Horsburgh, E. M., M.A., B.Sc., Lecturer in Technical Mathematics in the University of Edinburgh.

Year of Election.

1887. ‡Horsfall, T. C. Swanscoe Park, near Macclesfield.
1893. *Horsley, Sir Victor A. H., LL.D., B.Sc., F.R.S., F.R.C.S. (Council, 1893–98.) 25 Cavendish-square, W.
1908. §Horton, F. St. John's College, Cambridge.
1884. *Hotblack, G. S. Brundall, Norwich.
1899. ‡Hotblack, J. T., F.G.S. 45 Newmarket-road, Norwich.
1906. *Hough, Miss Ethel M. Codsall Wood, near Wolverhampton.
1859. ‡Hough, Joseph, M.A., F.R.A.S. Codsall Wood, Wolverhampton.
1896. *Hough, S. S., M.A., F.R.S., F.R.A.S., His Majesty's Astronomer at the Cape of Good Hope. Royal Observatory, Cape Town.
1905. §Houghting, A. G. L. Glenelg, Musgrave-road, Durban, Natal.
1905. ‡Houseman, C. L. P.O. Box 149, Johannesburg.
1908. ‡Houston, David, F.L.S. Royal College of Science, Dublin.
1883. *Hovenden, Frederick, F.L.S., F.G.S. Glenlea, Thurlow Park-road, West Dulwich, S.E.
1904. *Howard, Mrs. G. L. C. Agricultural Research Institute, Pusa, Bengal, India.
1887. *Howard, S. S. 54 Albemarle-road, Beckenham, Kent.
1901. §Howarth, E., F.R.A.S. Public Museum, Weston Park, Sheffield.
1903. *Howarth, James H., F.G.S. Somerley, Rawson-avenue, Halifax.
1907. ‡Howarth, O. J. R., M.A. (Assistant Secretary.) 24 Lansdowne-crescent, W.
1905. ‡Howick, Dr. W. P.O. Box 503, Johannesburg.
1901. ‡Howie, Robert Y. 3 Greenlaw-avenue, Paisley.
1863. ‡Howorth, Sir H. H., K.C.I.E., D.C.L., F.R.S., F.S.A. 30 Collingham-place, Cromwell-road, S.W.
1887. §Hoyle, William E., M.A., D.Sc. (Pres. D, 1907.) National Museum of Wales, City Hall, Cardiff.
1903. ‡Hübner, Julius. Ash Villa, Cheadle Hulme, Cheshire.
1898. ‡Hudson, Mrs. Sunny Bank, Egerton, Huddersfield.
1867. *Hudson, William H. H., M.A. 34 Birdhurst-road, Croydon.
1871. *Hughes, George Pringle, J.P., F.R.G.S. Middleton Hall, Wooler, Northumberland.
1868. §Hughes, T. M'K., M.A., F.R.S., F.G.S. (Council, 1879–86), Woodwardian Professor of Geology in the University of Cambridge. Ravensworth, Brooklands-avenue, Cambridge.
1867. ‡Hull, Edward, M.A., LL.D., F.R.S., F.G.S. (Pres. C, 1874.) 14 Stanley-gardens, Notting Hill, W.
1903. ‡Hulton, Campbell G. Palace Hotel, Southport.
1905. §Hume, D. G. W. P.O. Box 1132, Johannesburg.
1904. *Humphreys, Alexander C., Sc.D., LL.D., President of the Stevens Institute of Technology, Hoboken, New Jersey, U.S.A.
1907. §Humphries, Albert E. Coxe's Lock Mills, Weybridge.
1877. *Hunt, Arthur Roope, M.A., F.G.S. Southwood, Torquay.
1891. *Hunt, Cecil Arthur, Southwood, Torquay.
1881. ‡Hunter, F. W. 16 Old Elvet, Durham.
1889. ‡Hunter, Mrs. F. W. 16 Old Elvet, Durham.
1909. ‡Hunter, W. J. H. 31 Lynedoch-street, Glasgow.
1901. *Hunter, William. Evirallan, Stirling.
1903. ‡Hurst, Charles C., F.L.S. Burbage, Hinckley.
1861. *Hurst, William John. Drumaness, Ballynahinch, Co. Down, Ireland.
1894. *Hutchinson, A., M.A., Ph.D. (Local Sec. 1904.) Pembroke College, Cambridge.
1903. §Hutchinson, Rev. H. N. 17 St. John's Wood Park, Finchley-road, N.W.
1864. *Hutton, Darnton. 14 Cumberland-terrace, Regent's Park, N.W.

Year of Election.

1887. *Hutton, J. Arthur. The Woodlands, Alderley Edge, Cheshire.
1908. ‡Hutton, Lucius O. Wyckham, Dundrum, Co. Dublin.
1901. *Hutton, R. S., D.Sc. West-street, Sheffield.
1871. *Hyett, Francis A. Painswick House, Painswick, Stroud, Gloucestershire.
1900. *Hyndman, H. H. Francis. 5 Warwick-road, Earl's Court, S.W.

1908. ‡Idle, George. 43 Dawson-street, Dublin.
1883. ‡Idris, T. H. W. 110 Pratt-street, Camden Town, N.W.
Ihne, William, Ph.D. Heidelberg.
1884. *Iles, George. 5 Brunswick-street, Montreal, Canada.
1906. ‡Iliffe, J. W. Oak Tower, Upperthorpe, Sheffield.
1885. ‡im Thurn, Sir Everard F., C.B., K.C.M.G. 1 East India-avenue, Leadenhall-street, E.C.
1888. *Ince, Surgeon-Major John, M.D. Montague House, Swanley, Kent.
1907. §Ingham, Charles B. Moira House, Eastbourne.
1905. ‡Ingham, W. Engineer's Office, Sand River, Uitenhage.
1893. ‡Ingle, Herbert. Department of Agriculture, Pretoria.
1901. ‡INGLIS, JOHN, LL.D. 4 Prince's-terrace, Dowanhill, Glasgow.
1905. §Innes, R. T. A., F.R.A.S. Meteorological Observatory, Johannesburg.
1901. *Ionides, Stephen A. Georgetown, Colorado.
1882. §IRVING, Rev. A., B.A., D.Sc. Hockerill Vicarage, Bishop's Stortford, Herts.
1908. ‡Irwin, Alderman John. 33 Rutland-square, Dublin.

1876. *JACK, WILLIAM, LL.D., Professor of Mathematics in the University of Glasgow. 10 The University, Glasgow.
1909. §Jacks, Professor L. P. 28 Holywell, Oxford.
1883. *Jackson, Professor A. H., B.Sc. 349 Collins-street, Melbourne, Australia.
1903. ‡Jackson, C. S. Royal Military Academy, Woolwich, S.E.
1883. *Jackson, F. J. 35 Leyland-road, Southport.
1883. ‡Jackson, Mrs. F. J. 35 Leyland-road, Southport.
1874. *Jackson, Frederick Arthur. Belmont, Somenos, Vancouver Island, B.C., Canada.
1899. ‡Jackson, Geoffrey A. 31 Harrington-gardens, Kensington, S.W.
1897. §Jackson, James, F.R.Met.Soc. Seabank, Girvan, N.B.
1906. *Jackson, James Thomas, M.A. Engineering School, Trinity College, Dublin.
1898. *Jackson, Sir John. 51 Victoria-street, S.W.
1905. ‡Jacobsohn, Lewis B. Lloyd's-buildings, 58 Burg-street, Cape Town.
1905. ‡Jacobsohn, Sydney Samuel. Lloyd's-buildings, 58 Burg-street, Cape Town.
1887. §Jacobson, Nathaniel, J.P. Olive Mount, Cheetham Hill-road, Manchester.
1905. *Jaffé, Arthur, B.A. Strandtown, Belfast.
1874. *Jaffé, John. Villa Jaffé, 38 Promenade des Anglais, Nice, France.
1905. ‡Jagger, J. W. St. George's-street, Cape Town.
1906. ‡Jalland, W. H. Museum-street, York.
1891. *James, Charles Henry, J.P. 64 Park-place, Cardiff.
1891. *James, Charles Russell. 13 Hampstead Hill-gardens, N.W.
1904. ‡James, Thomas Campbell. University College, Aberystwyth.
1905. ‡Jameson, Adam. Office of the Commissioner of Lands, Pretoria.

Year of Election.

1896 *Jameson, H. Lyster, M.A., Ph.D. Transvaal Technical Institute, Johannesburg.
1881. ‡Jamieson, Professor Andrew, M.Inst.C.E., F.R.S.E. 16 Rosslyn-terrace, Kelvinside, Glasgow.
1859. *Jamieson, Thomas F., LL.D., F.G.S. Ellon, Aberdeenshire.
1889. *JAPP, F. R., M.A., Ph.D., LL.D., F.R.S. (Pres. B, 1898), Professor of Chemistry in the University of Aberdeen.
1910. *Japp, Henry, M.Inst.C.E. Care of Messrs. S. Pearson & Son, 507 Fifth Avenue, New York, U.S.A.
1896. *Jarmay, Gustav. Hartford Lodge, Hartford, Cheshire.
1903. ‡JARRATT, J. ERNEST (Local Sec. 1903). 10 Cambridge-road, Southport.
1904. *Jeans, J. H., M.A., F.R.S. Woodlands, Chaucer-road, Cambridge.
1897. ‡Jeffrey, E. C., B.A. The University, Toronto, Canada.
1908. *Jenkin, Arthur Pearse, F.R.Met.Soc. Trewirgie, Redruth.
1909. *Jenkins, Miss Emily Vaughan. Lyceum Club, 128 Piccadilly, W.
1903. ‡Jenkinson, J. W. The Museum, Oxford.
1904. ‡Jenkinson, W. W. 6 Moorgate-street, E.C.
1893. §Jennings, G. E. Glen Helen, Narborough-road, Leicester.
1905. ‡Jennings, Sydney. P.O. Box 149, Johannesburg.
1905. ‡Jerome, Charles. P.O. Box 83, Johannesburg.
1887. ‡JERVIS-SMITH, Rev. F. J., M.A., F.R.S. Trinity College, Oxford.
Jessop, William. Overton Hall, Ashover, Chesterfield.
1900. *Jevons, H. Stanley, M.A., B.Sc. Woodhill, Rhiwbeina, near Cardiff.
1907. *Jevons, Miss H. W. 19 Chesterford-gardens, Hampstead, N.W.
1905. §Jeyes, Miss Gertrude, B.A. Berrymead, 6 Lichfield-road, Kew Gardens.
1905. ‡Jobson, J. B. P.O. Box 3341, Johannesburg.
1909. *Johns, Cosmo, F.G.S., M.I.M.E. Burngrove, Pitsmoor-road, Sheffield.
1884. ‡JOHNSON, ALEXANDER, M.A., LL.D. 5 Prince of Wales-terrace, Montreal, Canada.
1909. §Johnson, C. Kelsall, F.R.G.S. The Glen, Sidmouth, Devon.
1865. *Johnson, G. J. 36 Waterloo-street, Birmingham.
1890. *JOHNSON, THOMAS, D.Sc., F.L.S., Professor of Botany in the Royal College of Science, Dublin.
1902. *Johnson, Rev. W., B.A., B.Sc. Archbishop Holgate's Grammar School, York.
1898. *Johnson, W. Claude, M.Inst.C.E. Broadstone, Coleman's Hatch, Sussex.
1899. ‡JOHNSTON, Colonel Sir DUNCAN A., K.C.M.G., C.B., R.E., Hon. Sec. R.G.S. (Pres. E, 1909.) Branksome, Saffrons-road, Eastbourne.
1883. ‡*JOHNSTON, Sir H. H., G.C.M.G., K.C.B., F.R.G.S. 27 Chester-terrace, Regent's Park, N.W.*
1909. §Johnston, J. Weir, M.A. 10 Lower Fitzwilliam-street, Dublin.
1908. ‡Johnston, Swift Paine. 1 Hume-street, Dublin.
1884. *Johnston, W. H. County Offices, Preston, Lancashire.
1885. ‡JOHNSTON-LAVIS, H. J., M.D., F.G.S. Beaulieu, Alpes-Maritimes, France.
1909. §Jolly, W. A., M.B. Physiological Laboratory, The University, Edinburgh.
1888. ‡JOLY, JOHN, M.A., D.Sc., F.R.S., F.G.S. (Pres. C, 1908), Professor of Geology and Mineralogy in the University of Dublin. Geological Department, Trinity College, Dublin.
1887. ‡Jones, D. E., B.Sc. Inglewood, Four Oaks, Sutton Coldfield.

Year of Election.

1904. §Jones, Miss E. E. Constance. Girton College, Cambridge.
1890. §JONES, Rev. EDWARD, F.G.S. Primrose Cottage, Embsay, Skipton.
1896. ‡Jones, E. Taylor, D.Sc. University College, Bangor.
1903. §Jones, Evan. Ty-Mawr, Aberdare.
1907. *Jones, Mrs. Evan. 12 Hyde Park-gate, S.W.
1887. ‡Jones, Francis, F.R.S.E., F.C.S. Beaufort House, Alexandra Park, Manchester.
1891. *JONES, Rev. G. HARTWELL, D.D. Nutfield Rectory, Redhill, Surrey.
1883. *Jones, George Oliver, M.A. Inchyra House, 21 Cambridge-road, Waterloo, Liverpool.
1903. *JONES, H. O., M.A. Clare College, Cambridge.
1905. ‡Jones, Miss Parnell. The Rectory, Llanddewi Skirrid, Abergavenny, Monmouthshire.
1901. ‡Jones, R. E., J.P. Oakley Grange, Shrewsbury.
1902. ‡Jones, R. M., M.A. Royal Academical Institution, Belfast.
1908. ‡Jones, R. Pugh, M.A. County School, Holyhead, Anglesey.
1860. ‡JONES, THOMAS RUPERT, F.R.S., F.G.S. (Pres. C, 1891.) Penbryn, Chesham Bois-lane, Chesham, Bucks.
1875. *Jose, J. E. Ethersall, Tarbock-road, Huyton, Lancashire.
1872. ‡Joy, Algernon. Junior United Service Club, St. James's, S.W.
1883. ‡Joyce, Rev. A. G., B.A. St. John's Croft, Winchester.
1886. ‡Joyce, Hon. Mrs. St. John's Croft, Winchester.
1905. ‡Judd, Miss Hilda M., B.Sc. Berrymead, 6 Lichfield-road, Kew.
1870. ‡JUDD, JOHN WESLEY, C.B., LL.D., F.R.S., F.G.S. (Pres. C, 1885; Council, 1886–92.) Orford Lodge, 30 Cumberland-road Kew.
1903. §JULIAN, HENRY FORBES. Redholme, Braddon's Hill-road, Torquay.
1894. §Julian, Mrs. Forbes. Redholme, Braddon's Hill-road, Torquay.
1905. §Juritz, Charles F., M.A., D.Sc., F.I.C. Government Analytical Laboratory, Parliament-street, Cape Town.

1888. ‡Kapp, Gisbert, M.Inst.C.E., M.Inst.E.E. Pen-y-Coed, Pritchatts-road, Birmingham.
1904. ‡Kayser, Professor H. The University, Bonn, Germany.
1892. ‡KEANE, CHARLES A., Ph.D. Sir John Cass Technical Institute, Jewry-street, Aldgate, E.C.
1908. §Keeble, Frederick, Sc.D. University College, Reading.
1878. *Kelland, W. H. 27 Canterbury-road, Brixton, S.W.
1884. ‡Kellogg, J. H., M.D. Battle Creek, Michigan, U.S.A.
1908. §Kelly, Malachy. Ard Brugh, Dalkey, Co. Dublin.
1908. ‡Kelly, Captain Vincent Joseph. Montrose, Donnybrook, Co. Dublin.
1902. *Kelly, William J., J.P. 25 Oxford-street, Belfast.
1885. §KELTIE, J. SCOTT, LL.D., Sec. R.G.S., F.S.S. (Pres. E, 1897; Council, 1898–1904.) 1 Savile-row, W.
1877. *Kelvin, Lady. Netherhall, Largs, Ayrshire; and 15 Eaton-place, S.W.
1887. ‡Kemp, Harry. 55 Wilbraham-road, Chorlton-cum-Hardy, Manchester.
1898. *Kemp, John T., M.A. 4 Cotham-grove, Bristol.
1884. ‡Kemper, Andrew C., A.M., M.D. 101 Broadway, Cincinnati, U.S.A.
1891. ‡KENDALL, PERCY F., M.Sc., F.G.S., Professor of Geology in the University of Leeds.
1875. ‡KENNEDY, Sir ALEXANDER B. W., LL.D., F.R.S., M.Inst.C.E. (Pres. G, 1894.) 1 Queen Anne-street, Cavendish-square, W.

Year of Election.

1906. ‡Kennedy, Alfred Joseph, F.R.G.S. Care of Williams Deacon's Bank, Ltd., 2 Cockspur-street, S.W.
1897. §Kennedy, George, M.A., LL.D., K.C. Crown Lands Department, Toronto, Canada.
1906. ‡Kennedy, Robert Sinclair. Glengall Ironworks, Millwall, E.
1908. ‡Kennedy, William. 40 Trinity College, Dublin.
1905. *Kennerley, W. R. P.O. Box 158, Pretoria.
1893. §Kent, A. F. Stanley, M.A., F.L.S., F.G.S., Professor of Physiology in the University of Bristol.
1901. ‡Kent, G. 16 Premier-road, Nottingham.
1857. *Ker, André Allen Murray. Newbliss House, Newbliss, Ireland.
1909. ‡Kerr, Hugh L. 68 Admiral-road, Toronto, Canada.
1892. ‡Kerr, J. Graham, M.A., F.R.S., Regius Professor of Zoology in the University of Glasgow.
1889. ‡Kerry, W. H. R. The Sycamores, Windermere.
1910. §Kershaw, J. B. C. West Lancashire Laboratory, Waterloo, Liverpool.
1869. *Kesselmeyer, Charles Augustus. Roseville, Vale-road, Bowdon, Cheshire.
1869. *Kesselmeyer, William Johannes. Edelweiss Villa, Albert-road, Hale, Cheshire.
1903. ‡Kewley, James. Balek Papan, Koltei, Dutch Borneo.
1883. *Keynes, J. N., M.A., D.Sc., F.S.S. 6 Harvey-road, Cambridge.
1905. ‡Kidd, Professor A. Stanley. Rhodes University College, Grahamstown, Cape Colony.
1902. ‡Kidd, George. Greenhaven, Malone Park, Belfast.
1906. ‡Kidner, Henry, F.G.S. 25 Upper Rock-gardens, Brighton.
1886. §Kidston, Robert, LL.D., F.R.S., F.R.S.E., F.G.S. 12 Clarendon-place, Stirling.
1901. **Kiep, J. N. 4 Hughenden-terrace, Kelvinside, Glasgow.*
1885. *Kilgour, Alexander. Loirston House, Cove, near Aberdeen.
1896. *Killey, George Deane, J.P. Bentuther, 11 Victoria-road, Waterloo, Liverpool.
1890. ‡Kimmins, C. W., M.A., D.Sc. Dame Armstrong House, Harrow.
1875. *Kinch, Edward, F.I.C., Professor of Chemistry in the Royal Agricultural College, Cirencester.
1888. *King, E. Powell. Wainsford, Lymington, Hants.
1875. *King, F. Ambrose. Avonside, Clifton, Bristol.
1871. *King, Rev. Herbert Poole. The Rectory, Stourton, Bath.
1883. *King, John Godwin. Stonelands, East Grinstead.
1883. *King, Joseph, M.P. Sandhouse, Witley, Godalming.
1908. §King, Professor L. A. L., M.A. St. Mungo's College Medical School, Glasgow.
1860. *King, Mervyn Kersteman. Merchants' Hall, Bristol.
1875. *King, Percy L. 2 Worcester-avenue, Clifton, Bristol.
1870. ‡King, William, M.Inst.C.E. 5 Beach-lawn, Waterloo, Liverpool.
1909. ‡Kingdon, A. 197 Yale-avenue, Winnipeg, Canada.
1903. §Kingsford, H. S., M.A. 60 Clapton-common, N.E.
1900. ‡Kipping, Professor F. Stanley, D.Sc., Ph.D., F.R.S. (Pres. B, 1908.) University College, Nottingham.
1899. *Kirby, Miss C. F. 8 Windsor-court, Moscow-road, W.
1907. §Kirby, William Forsell, F.L.S. Hilden, 46 Sutton Court-road, Chiswick, W.
1905. ‡Kirkby, Reginald G. P.O. Box 7, Pietermaritzburg, Natal.
1901. §Kitto, Edward. The Observatory, Falmouth.
1886. ‡Knight, Captain J. M., F.G.S. Bushwood, Wanstead, Essex.
1905. §Knightley, Lady, of Fawsley. Fawsley Park, Daventry.

Year of Election.

1888. ‡KNOTT, Professor CARGILL G., D.Sc., F.R.S.E. 42 Upper Gray-street, Edinburgh.
1887. *Knott, Herbert, J.P. Sunnybank, Wilmslow, Cheshire.
1887. *Knott, John F. Nant-y-Coed, Conway, North Wales.
1906. *Knowles, Arthur J., B.A., M.Inst.C.E. Turf Club, Cairo, Egypt.
1874. ‡Knowles, William James. Flixton-place, Ballymena, Co. Antrim.
1903. ‡Knowlson, J. F. 26 Part-street, Southport.
1902. ‡KNOX, R. KYLE, LL.D. 1 College-gardens, Belfast.
1875. *Knubley, Rev. E. P., M.A. Steeple Ashton Vicarage, Trowbridge.
1883. ‡Knubley, Mrs. Steeple Ashton Vicarage, Trowbridge.
1905. ‡Koenig, J. P.O. Box 272, Cape Town.
1890. *Krauss, John Samuel, B.A. Stonycroft, Knutsford-road, Wilmslow, Cheshire.
1888 *Kunz, G. F., M.A., Ph.D. Care of Messrs. Tiffany & Co., 11 Union-square, New York City, U.S.A.

1905. ‡Lacey, William. Champ d'Or Gold Mining Co., Luipaardsvlei, Transvaal.
1903. *Lafontaine, Rev. H. C. de. 49 Albert-court, Kensington Gore, S.W.
1909. ‡Laird, Hon. David. Indian Commission, Ottawa, Canada.
1904. ‡Lake, Philip. St. John's College, Cambridge.
1904. ‡Lamb, C. G. Ely Villa, Glisson-road, Cambridge.
1889. *Lamb, Edmund, M.A. Borden Wood, Liphook, Hants.
1887. ‡LAMB, HORACE, M.A., LL.D., D.Sc., F.R.S. (Pres. A, 1904), Professor of Pure Mathematics in the Victoria University, Manchester. 6 Wilbraham-road, Fallowfield, Manchester.
1909. ‡*Lamb, J. R.* *389 Graham-avenue, Winnipeg, Canada.*
1903. ‡Lambert, Joseph. 9 Westmoreland-road, Southport.
1893. *LAMPLUGH, G. W., F.R.S., F.G.S. (Pres. C, 1906.) 13 Beaconsfield-road, St. Albans.
1905. ‡Lane, Rev. C. A. P.O. Box 326, Johannesburg.
1898. *LANG, WILLIAM H. 2 Heaton-road, Withington, Manchester.
1905. §Lange, John H. Judges' Chambers, Kimberley.
1886. *LANGLEY, J. N., M.A., D.Sc., F.R.S. (Pres. I, 1899; Council, 1904–07), Professor of Physiology in the University of Cambridge. Trinity College, Cambridge.
1865. ‡LANKESTER, Sir E. RAY, K.C.B., M.A., LL.D., D.Sc., F.R.S. (PRESIDENT, 1906; Pres. D, 1883; Council, 1889–90, 1894–95, 1900–02.) 29 Thurloe-place, S.W.
1880. *LANSDELL, Rev. HENRY, D.D., F.R.A.S., F.R.G.S. Morden College, Blackheath, London, S.E.
1884. ‡Lanza, Professor G. Massachusetts Institute of Technology, Boston, U.S.A.
1885. ‡LAPWORTH, CHARLES, LL.D., F.R.S., F.G.S. (Pres. C, 1892), Professor of Geology and Physiography in the University of Birmingham. 48 Frederick-road, Edgbaston, Birmingham.
1909. §Larard, C. E., A.M.Inst.C.E. 106 Cranley-gardens, Muswell Hill, N.
1887. ‡Larmor, Alexander. Craglands, Helen's Bay, Co. Down.
1881. ‡LARMOR, Sir JOSEPH, M.A., D.Sc., Sec.R.S. (Pres. A, 1900), Lucasian Professor of Mathematics in the University of Cambridge. St. John's College, Cambridge.
1883. ‡Lascelles, B. P., M.A. Headland, Mount Park, Harrow.
1896. *Last, William I. Science Museum, London, S.W.
1870. *LATHAM, BALDWIN, M.Inst.C.E., F.G.S. Parliament-mansions, Westminster, S.W.

Year of Election.

1900. ‡Lauder, Alexander, Lecturer in Agricultural Chemistry in the Edinburgh and East of Scotland College of Agriculture, Edinburgh.
1892. ‡LAURIE, MALCOLM, B.A., D.Sc., F.L.S. School of Medicine, Surgeons' Hall, Edinburgh.
1883. ‡Laurie, Lieut.-General. 47 Porchester-terrace, W.
1907. *Laurie, Robert Douglas. Department of Zoology, The University, Liverpool.
1870. *Law, Channell. Ilsham Dene, Torquay.
1905. ‡Lawrence, Miss M. Roedean School, near Brighton.
1908. §Lawson, H. S., B.A. Harben, Compton-road, Wolverhampton.
1908. ‡Lawson, William, LL.D. 27 Upper Fitzwilliam-street, Dublin.
1888. ‡Layard, Miss Nina F., F.L.S. Rookwood, Fonnereau-road, Ipswich.
1883. *Leach, Charles Catterall. Seghill, Northumberland.
1894. *LEAHY, A. H., M.A., Professor of Mathematics in the University of Sheffield. 92 Ashdell-road, Sheffield.
1905. ‡Leake, E. O. 5 Harrison-street, Johannesburg.
1901. *Lean, George, B.Sc. 15 Park-terrace, Glasgow.
1904. *Leathem, J. G. St. John's College, Cambridge.
1884. *Leavitt, Erasmus Darwin. 2 Central-square, Cambridgeport, Massachusetts, U.S.A.
1872. ‡LEBOUR, G. A., M.A., F.G.S., Professor of Geology in the Durham College of Science, Newcastle-on-Tyne.
1910. §Lebour, Miss M. V., M.Sc. Zoological Department, The University, Leeds.
1895. *Ledger, Rev. Edmund. Protea, Doods-road, Reigate.
1907. ‡Lee, Mrs. Barton. 126 Mile End-lane, Stockport.
1910. *Lee, Ernest. 2 Claughton-street, Burnley, Lancashire.
1896. §Lee, Rev. H. J. Barton. 126 Mile End-lane, Stockport.
1909. §Lee, I. L. Care of Messrs. Harris, Winthrop, & Co., 24 Throgmorton-street, E.C.
1909. §Lee, Rev. J. W., D.D. 5068 Washington-avenue, St. Louis, Missouri, U.S.A.
1894. *Lee, Mrs. W. Ashdown House, Forest Row, Sussex.
1884. *Leech, Sir Bosdin T. Oak Mount, Timperley, Cheshire.
1909. ‡Leeming, J. H., M.D. 406 Devon-court, Winnipeg, Canada.
1905. §Lees, Mrs. A. P. Care of Dr. Norris Wolfenden, 76 Wimpole-street, W.
1892. *LEES, CHARLES H., D.Sc., F.R.S., Professor of Physics in the East London College, Mile End. Greenacres, Mayfield-avenue, Woodford Green, Essex.
1886. *Lees, Lawrence W. Old Ivy House, Tettenhall, Wolverhampton.
1906. ‡Lees, Robert. Victoria-street, Fraserburgh.
1905. ‡Lees, R. Wilfrid. Pigg's Peak Development Co., Swaziland, South Africa.
1889. *Leeson, John Rudd, M.D., C.M., F.L.S., F.G.S. Clifden House, Twickenham, Middlesex.
1906. ‡Leetham, Sidney. Elm Bank, York.
1905. ‡Legg, W. A. P.O. Box 1621, Cape Town.
1892. ‡LEHFELDT, ROBERT A. 56 *Norfolk-square, W.*
1910. §Leigh, H. S. Brentwood, Worsley, near Manchester.
1891. ‡Leigh, W. W. Glyn Bargoed, Treharris, R.S.O., Glamorganshire.
1903. ‡Leighton, G. R., M.D., F.R.S.E., Professor of Pathology in the Royal Veterinary College, Edinburgh.
1906. ‡Leiper, Robert T., M.B., F.Z.S. London School of Tropical Medicine, Royal Albert Dock, E.

Year of Election.

1905. ‡Leitch, Donald. P.O. Box 1703, Johannesburg.
1882. §Lemon, Sir James, M.Inst.C.E., F.G.S. 11 The Avenue, Southampton.
1903. *Lempfert, R. G. K., M.A. 66 Sydney-street, S.W.
1908. ‡Lentaigne, John. 42 Merrion-square, Dublin.
1887. *Leon, John T. Elmwood, Grove-road, Southsea.
1901. §LEONARD, J. H., B.Sc. 13 Gunterstone-road, West Kensington, W.
1905. ‡Leonard, Right Rev. Bishop John. St. Mary's, Cape Town.
1890. *Lester, Joseph Henry, Royal Exchange, Manchester.
1904. *Le Sueur, H. R., D.Sc. Chemical Laboratory, St. Thomas's Hospital, S.E.
1900. ‡Letts, Professor E. A., D.Sc., F.R.S.E. Queen's College, Belfast.
1896. ‡Lever, W. H. Thornton Manor, Thornton Hough, Cheshire.
1905. ‡Levin, Benjamin. P.O. Box 74, Cape Town.
1887. *Levinstein, Ivan. Hawkesmoor, Fallowfield, Manchester.
1893. *LEWES, VIVIAN B., F.C.S., Professor of Chemistry in the Royal Naval College, Greenwich, S.E.
1905. ‡Lewin, J. B. Duncan's-chambers, Shortmarket-street, Cape Town.
1904. *Lewis, Mrs. Agnes S., LL.D. Castle Brae, Chesterton-lane, Cambridge.
1870. ‡LEWIS, ALFRED LIONEL. 35 Beddington-gardens, Wallington, Surrey.
1891. ‡Lewis, Professor D. Morgan, M.A. University College, Aberystwyth.
1899. ‡Lewis, Professor E. P. University of California, Berkeley, U.S.A.
1905. ‡Lewis, F. S., M.A. South African Public Library, Cape Town.
1910. §LEWIS, FRANCIS J., M.Sc. The University, Liverpool.
1904. ‡Lewis, Hugh. Glanafrau, Newtown, Montgomeryshire.
1910. *Lewis, T. C. West Home, West-road, Cambridge.
1884. *Lewis, Sir W. T., Bart. The Mardy, Aberdare.
1903. ‡Lewkowitsch, Dr. J. 71 Priory-road, N.W.
1906. §Liddiard, James Edward, F.R.G.S. Rodborough Grange, Bournemouth.
1908. ‡Lilly, W. E., M.A., Sc.D. 39 Trinity College, Dublin.
1904. ‡Link, Charles W. 14 Chichester-road, Croydon.
1898. ‡Lippincott, R. C. Cann. Over Court, near Bristol.
1895. *LISTER, The Right Hon. Lord, O.M., F.R.C.S., D.C.L., D.Sc., F.R.S. (PRESIDENT, 1896.) 12 Park-crescent, Portland-place, W.
1888. ‡LISTER, J. J., M.A., F.R.S. (Pres. D, 1906.) St. John's College, Cambridge.
1861. *LIVEING, G. D., M.A., F.R.S. (Pres. B, 1882; Council 1888–95; Local Sec. 1862.) Newnham, Cambridge.
1876. *LIVERSIDGE, ARCHIBALD, M.A., F.R.S., F.C.S., F.G.S., F.R.G.S. Hornton Cottage, Hornton-street, Kensington, W.
1902. §Llewellyn, Evan. Working Men's Institute and Hall, Blaenavon.
1909. §Lloyd, George C., Secretary of the Iron and Steel Institute. 28 Victoria-street, S.W.
1903. ‡Lloyd, Godfrey I. H. The University of Toronto, Canada.
1891. **LLOYD, R. J., M.A., D.Litt., F.R.S.E. 49A Grove-street, Liverpool.*
1854. *LOBLEY, J. LOGAN, F.G.S., F.R.G.S. 36 Palace-street, Buckingham Gate, S.W.
1892. ‡LOCH, C. S., D.C.L. Denison House, Vauxhall Bridge-road, S.W.
1905. ‡Lochrane, Miss T. 8 Prince's-gardens, Dowanhill, Glasgow.
1904. ‡Lock, Rev. J. B. Herschel House, Cambridge.
1863. ‡LOCKYER, Sir J. NORMAN, K.C.B., LL.D., D.Sc., F.R.S. (PRESIDENT, 1903; Council, 1871–76, 1901–02.) 16 Penywern-road, S.W.
1902. *Lockyer, Lady. 16 Penywern-road, S.W.

Year of Election.

1900. §Lockyer, W. J. S., Ph.D. 16 Penywern-road, S.W.
1886. *Lodge, Alfred, M.A. The Croft, Peperharow-road, Godalming.
1875. *Lodge, Sir Oliver J., D.Sc., LL.D., F.R.S. (Pres. A, 1891: Council, 1891-97, 1899-1903), Principal of the University of Birmingham.
1894. **Lodge, Oliver W. F.* 17 *Ruskin-buildings, Westminster, S.W.*
1899. §Loncq, Emile. 6 Rue de la Plaine, Laon, Aisne, France.
1902. ‡Londonderry, The Marquess of, K.G. Londonderry House, Park-lane, W.
1903. ‡Long, Frederick. The Close, Norwich.
1905. ‡Long, W. F. City Engineer's Office, Cape Town.
1883. *Long, William. Thelwall Heys, near Warrington.
1904. *Longden, J. A., M.Inst.C.E. Stanton-by-Dale, Nottingham.
1905. §Longden, Mrs. J. B. Stanton-by-Dale, Nottingham.
1898. *Longfield, Miss Gertrude. Belmont, High Halstow, Rochester.
1901. *Longstaff, Frederick V., F.R.G.S. Ridgelands, Wimbledon, Surrey.
1875. *Longstaff, George Blundell, M.A., M.D., F.C.S., F.S.S. Highlands, Putney Heath, S.W.
1872. *Longstaff, Llewellyn Wood, F.R.G.S. Ridgelands, Wimbledon, S.W.
1881. *Longstaff, Mrs. Ll. W. Ridgelands, Wimbledon, S.W.
1899. *Longstaff, Tom G., M.A., M.D. Ridgelands, Wimbledon, S.W.
1903. ‡Loton, John, M.A. 23 Hawkshead-street, Southport.
1897. ‡Loudon, James, LL.D., President of the University of Toronto, Canada.
1883. *Louis, D. A., F.G.S., F.I.C. 123 Pall Mall, S.W.
1896. §Louis, Henry, D.Sc., Professor of Mining in the Armstrong College of Science, Newcastle-on-Tyne.
1887. *Love, A. E. H., M.A., D.Sc., F.R.S. (Pres. A, 1907), Professor of Natural Philosophy in the University of Oxford. 34 St. Margaret's-road, Oxford.
1886. *Love, E. F. J. M.A., D.Sc. The University, Melbourne, Australia.
1904. *Love, J. B. Outlands, Devonport.
1876. *Love, James, F.R.A.S., F.G.S., F.Z.S. 33 Clanricarde-gardens, W.
1905. ‡Loveday, Professor T. South African College, Cape Town.
1908. §Low, Alexander, M.A., M.B. The University, Aberdeen.
1909. ‡Low, David, M.D. 1927 Scarth-street, Regina, Saskatchewan, Canada.
1885. §Lowdell, Sydney Poole. Baldwin's Hill, East Grinstead, Sussex.
1891. §Lowdon, John. St. Hilda's, Barry, Glamorgan.
1885. *Lowe, Arthur C. W. Gosfield Hall, Halstead, Essex.
1905. ‡Lowe, E. C. Chamber of Trade, Johannesburg.
1836. *Lowe, John Landor, B.Sc., M.Inst.C.E. Spondon, Derbyshire.
1894. ‡Lowenthal, Miss Nellie. Woodside, Egerton, Huddersfield.
1903. *Lowry, Dr. T. Martin. 130 Horseferry-road, S.W.
1901. *Lucas, Keith. Trinity College, Cambridge.
1891. *Lucovich, Count A. Tyn-y-parc, Whitchurch, near Cardiff.
1906. §Ludlam, Ernest Bowman. College Gate, 32 College-road, Clifton, Bristol.
1866. *Lund, Charles. Ilkley, Yorkshire.
1850. *Lundie, Cornelius. 32 Newport-road, Cardiff.
1905. ‡Lunnon, F. J. P.O. Box 400, Pretoria.
1883. *Lupton, Arnold, M.P., M.Inst.C.E., F.G.S. 7 Victoria-street, S.W.
1874. *Lupton, Sydney, M.A. (Local Sec. 1890.) 102 Park-street, Grosvenor-square, W.
1898. §Luxmoore, Dr. C. M., F.I.C., 19 Disraeli-gardens, Putney, S.W.
1903. ‡Lyddon, Ernest H. Lisvane, near Cardiff.
1884. ‡Lyman, H. H. 384 St. Paul-street, Montreal, Canada.

Year of Election.

1907. *Lyons, Captain Henry George, D.Sc., F.R.S. 34 Huntly-gardens, Glasgow.
1908. ‡Lyster, George H. 34 Dawson-street, Dublin.
1908. ‡Lyster, Thomas W., M.A. National Library of Ireland, Kildare-street, Dublin.

1905. ‡Maberly, Dr. John. Shirley House, Woodstock, Cape Colony.
1868. ‡MACALISTER, ALEXANDER, M.A., M.D., F.R.S. (Pres. H, 1892; Council, 1901–06), Professor of Anatomy in the University of Cambridge. Torrisdale, Cambridge.
1878. ‡MACALISTER, Sir DONALD, K.C.B., M.A., M.D., LL.D., B.Sc., Principal of the University of Glasgow.
1904. ‡Macalister, Miss M. A. M. Torrisdale, Cambridge.
1908. ‡Macallan, J., F.I.C., F.R.S.E. 3 Rutland-terrace, Clontarf, Co. Dublin.
1896. ‡MACALLUM, Professor A. B., Ph.D., D.Sc., F.R.S. (Pres. I, 1910; Local Sec. 1897.) 59 St. George-street, Toronto, Canada.
1879. §MacAndrew, James J., F.L.S. Lukesland, Ivybridge, South Devon.
1883. ‡MacAndrew, Mrs. J. J. Lukesland, Ivybridge, South Devon.
1909. §MacArthur, J. A., M.D. Canada Life Building, Winnipeg, Canada.
1896. *Macaulay, F. S., M.A. 19 Dewhurst-road, W.
1904. *Macaulay, W. H. King's College, Cambridge.
1896. ‡MACBRIDE, Professor E. W., M.A., D.Sc., F.R.S. Imperial College of Science and Technology, S.W.
1902. *Maccall, W. T., M.Sc. Technical College, Sunderland.
1886. ‡MacCarthy, Rev. E. F. M., M.A 50 Harborne-road, Edgbaston, Birmingham.
1908. §McCarthy, Edward Valentine, J.P. Ardmanagh House, Glenbrook, Co. Cork.
1909. ‡McCarthy, J. H. Public Library, Winnipeg, Canada.
1884. *McCarthy, J. J., M.D. 83 Wellington-road, Dublin.
1887. *McCarthy, James. 1 Sydney-place, Bath.
1904. §McClean, Frank Kennedy. Rusthall House, Tunbridge Wells.
1902. ‡McClelland, J. A., M.A., F.R.S., Professor of Physics in University College, Dublin.
1906. ‡McClure, Rev. E. 80 Eccleston-square, S.W.
1878. *M'Comas, Henry. Pembroke House, Pembroke-road, Dublin.
1908. §McCombie, Hamilton, M.A., Ph.D. The University, Birmingham.
1901. *MacConkey, Alfred. Queensberry Lodge, Elstree, Herts.
1905. ‡McConnell, D. E. Montrose-avenue, Orangezicht, Cape Town.
1901. ‡MacCormac, J. M., M.D. 31 Victoria-place, Belfast.
1892. *McCowan, John, M.A., D.Sc. Henderson-street, Bridge of Allan N.B.
1901. ‡McCrae, John, Ph.D. 7 Kirklee-gardens, Glasgow.
1905. §McCulloch, Principal J. D. Free College, Edinburgh.
1904. ‡McCulloch, Major T., R.A. 68 Victoria-street, S.W.
1909. ‡MacDonald, Miss Eleanor. Fort Qu'Appelle, Saskatchewan, Canada.
1904. ‡Macdonald, H. M., M.A., F.R.S., Professor of Mathematics in the University of Aberdeen.
1905. ‡McDonald, J. G. P.O. Box 67, Bulawayo.
1900. ‡MacDonald, J. Ramsay, M.P. 3 Lincoln's Inn-fields, W.C.
1890. *MacDonald, Mrs. J. Ramsay. 3 Lincoln's Inn-fields, W.C.
1905. §Macdonald, J. S., B.A., Professor of Physiology in the University of Sheffield.
1884. *Macdonald, Sir W. C. 449 Sherbrooke-street West, Montreal, Canada.

Year of Election.

1909. ‡MacDonell, John, M.D. Portage-avenue, Winnipeg, Canada.
1909. *MacDougall, R. Stewart. The University, Edinburgh.
1908. §McEwen, Walter, J.P. Flowerbank, Newton Stewart, Scotland.
1897. ‡McEwen, William C. 9 South Charlotte-street, Edinburgh.
1881. ‡Macfarlane, Alexander, D.Sc., F.R.S.E. 317 Victoria-avenue, Chatham, Ontario, Canada.
1906. §McFarlane, John. 30 Parsonage-road, Withington, Manchester.
1885. ‡Macfarlane, J. M., D.Sc., F.R.S.E., Professor of Biology in the University of Pennsylvania, Lansdowne, Delaware Co., Pennsylvania, U.S.A.
1905. ‡Macfarlane, T. J. M. P.O. Box 1198, Johannesburg.
1901. ‡Macfee, John. 5 Greenlaw-terrace, Paisley.
1909. ‡Macgachen, A. F. D. 281 River-avenue, Winnipeg, Canada.
1888. ‡MacGeorge, James. 8 Matheson-road, Kensington, W.
1908. ‡McGrath, Joseph, LL.D. (Local Sec. 1908.) Royal University of Ireland, Dublin.
1908. §MacGregor, Charles. Training Centre, Charlotte-street, Aberdeen.
1906. ‡Macgregor, D. H., M.A. Trinity College, Cambridge.
1884. *MacGregor, James Gordon, M.A., D.Sc., F.R.S., F.R.S.E., Professor of Natural Philosophy in the University of Edinburgh.
1902. ‡McIlroy, Archibald. Glenvale, Drumbo, Lisburn, Ireland.
1905. ‡Macindoe, Flowerdue. 23 Saratoga-avenue, Johannesburg.
1867. *McIntosh W. C., M.D., LL.D., F.R.S., F.R.S.E., F.L.S. (Pres. D, 1885), Professor of Natural History in the University of St. Andrews. 2 Abbotsford-crescent, St. Andrews, N.B.
1909. ‡McIntyre, Alexander. 142 Maryland-avenue, Winnipeg, Canada.
1909. ‡McIntyre, Daniel. School Board Offices, Winnipeg, Canada.
1909. ‡McIntyre, W. A. 339 Kennedy-street, Winnipeg, Canada.
1884. §MacKay, A. H., B.Sc., LL.D., Superintendent of Education. Education Office, Halifax, Nova Scotia, Canada.
1885. ‡Mackay, John Yule, M.D., LL.D., Principal of and Professor of Anatomy in University College, Dundee.
1908. ‡McKay, William, J.P. Clifford-chambers, York.
1909. §McKee, Dr. E. S. Grand and Nassau-streets, Cincinnati, U.S.A.
1873. ‡McKendrick, John G., M.D., LL.D., F.R.S., F.R.S.E. (Pres. I, 1901; Council, 1903-09), Emeritus Professor of Physiology in the University of Glasgow. Maxieburn, Stonehaven, N.B.
1909. ‡McKenty, D. E. 104 Colony-street, Winnipeg, Canada.
1905. ‡McKenzie, A. R. P.O. Box 214, Cape Town.
1905. ‡Mackenzie, Hector. Standard Bank of South Africa, Cape Town.
1897. ‡McKenzie, John J. 61 Madison-avenue, Toronto, Canada.
1910. §Mackenzie, K. J. J., M.A. 10 Richmond-road, Cambridge.
1909. §MacKenzie, Kenneth. Royal Alexandra Hotel, Winnipeg, Canada.
1901. *Mackenzie, Thomas Brown. Netherby, Manse-road, Motherwell, N.B.
1872. *Mackey, J. A. United University Club, Pall Mall East, S.W.
1901. ‡Mackie, William, M.D. 13 North-street, Elgin.
1887. ‡Mackinder, H. J., M.A., M.P., F.R.G.S. (Pres. E, 1895; Council, 1904-1905.) 243 St. James's-court, Buckingham-gate, S.W.
1908. §MacKinnon, Mrs. Donald. Speldhurst Rectory, Tunbridge Wells.
1893. *McLaren, Mrs. E. L. Colby, M.B., Ch.B. 133 Tettenhall-road, Wolverhampton.
1901. ‡Maclaren, J. Malcolm. Royal Colonial Institute, Northumberland Avenue, W.C.
1905. ‡McLaren, Thomas. P.O. Box 1034, Johannesburg.
1901. ‡Maclay, William. Thornwood, Langside, Glasgow.
1901. ‡McLean, Angus, B.Sc. Harvale, Meikleriggs, Paisley.

Year of Election.

1892. *Maclean, Magnus, M.A., D.Sc., F.R.S.E. (Local Sec. 1901), Professor of Electrical Engineering, Technical College, Glasgow.
1909. ‡MacLean, Neil Bruce. 24 Hitchcock Hall, The University, Chicago, U.S.A.
1908. §McLennan, J. C., Professor of Physics in the University of Toronto, Canada.
1868. ‡McLeod, Herbert, F.R.S. (Pres. B, 1892; Council, 1885–90.) 37 Montague-road, Richmond, Surrey.
1909. ‡MacLeod, M. H. C.N.R. Depôt, Winnipeg, Canada.
1883. ‡MacMahon, Major Percy A., R.A., D.Sc., F.R.S. (General Secretary, 1902– ; Pres. A, 1901; Council, 1898–1902.) 27 Evelyn-mansions, Carlisle-place, S.W.
1909. ‡McMillan, The Hon. Sir Daniel H., K.C.M.G. Government House, Winnipeg, Canada.
1902. ‡McMordie, Robert J. Cabin Hill, Knock, Co. Down.
1905. ‡MacNay, Arthur. Cape Government Railway Offices, De Aar, Cape Colony.
1878. ‡Macnie, George. 59 Bolton-street, Dublin.
1905. ‡Macphail, Dr. S. Rutherford. Rowditch, Derby.
1909. §MacPhail, W. M. P.O. Box 88, Winnipeg, Canada.
1905. ‡Macrae, Harold J. P.O. Box 817, Johannesburg.
1907. ‡Macrosty, Henry W. 29 Hervey-road, Blackheath, S.E.
1906. ‡Macturk, G. W. B. 15 Bowlalley-lane, Hull.
1908. ‡McVittie, R. B., M.D. 62 Fitzwilliam-square North, Dublin.
1908. ‡McWalter, J. C., M.D., M.A. 19 North Earl-street, Dublin.
1902. ‡McWeeney, Professor E. J., M.D. 84 St. Stephen's-green, Dublin.
1902. ‡*McWhirter, William. 9 Walworth-terrace, Glasgow.*
1910. §McWilliam, Andrew, Professor of Metallurgy in the University of Sheffield.
1908. ‡Madden, Rt. Hon. Mr. Justice. Nutley, Booterstown, Dublin.
1905. ‡Magenis, Lady Louisa. 34 Lennox-gardens, S.W.
1902. ‡*Magill, R., M.A., Ph.D. The Manse, Maghera, Co. Derry.*
1909. ‡Magnus, Laurie, M.A. 12 Westbourne-terrace, W.
1875. *Magnus, Sir Philip, B.Sc., B.A., M.P. (Pres. L, 1907). 16 Gloucester-terrace, Hyde Park, W.
1908. *Magson, Egbert H. 67 Pepys-road, Cottenham Park, Wimbledon, S.W.
1902. ‡*Mahon, J. L. 2 May-street, Drumcondra, Dublin.*
1907. *Mair, David. Civil Service Commission, Burlington-gardens, W.
1908. ‡Mair, William, F.C.S. 7 Coniston-road, Edinburgh.
1908. *Makower, W. The University, Manchester.
1857. ‡Mallet, John William, Ph.D., M.D., F.R.S., F.C.S., Professor of Chemistry in the University of Virginia, Albemarle Co., U.S.A.
1905. ‡Maltby, Lieutenant G. R., R.N. 54 St. George's-square, S.W.
1897. ‡Mance, Sir H. C. Old Woodbury, Sandy, Bedfordshire.
1903. ‡Manifold, C. C. 16 St. James's-square, S.W.
1905. ‡Manning, D. W., F.R.G.S. Roydon, Rosebank, Cape Town.
1894. ‡Manning, Percy, M.A., F.S.A. Watford, Herts.
1905. ‡Mansfield, J. D. 94 St. George's-street, Cape Town.
1887. *March, Henry Colley, M.D., F.S.A. Portesham, Dorchester, Dorsetshire.
1902. *Marchant, Dr. E. W. The University, Liverpool.
1898. *Mardon, Heber. 2 Litfield-place, Clifton, Bristol.
1900. ‡Margerison, Samuel. Calverley Lodge, near Leeds.
1864. ‡Markham, Sir Clements R., K.C.B., F.R.S., F.R.G.S., F.S.A. (Pres. E, 1879; Council, 1893–96.) 21 Eccleston-square, S.W.
1905. §Marks, Samuel. P.O. Box 379, Pretoria.

Year of Election.

1905. ‡Marloth, R., M.A., Ph.D. P.O. Box 359, Cape Town.
1881. *MARR, J. E., M.A., D.Sc., F.R.S., F.G.S. (Pres. C, 1896; Council, 1896–1902, 1910– .) St. John's College, Cambridge.
1903. §Marriott, William. Royal Meteorological Society, 70 Victoria-street, S.W.
1892. *Marsden-Smedley, J. B. Lea Green, Cromford, Derbyshire.
1883. *Marsh, Henry Carpenter. 3 Lower James-street, Golden-square, W.
1887. ‡Marsh, J. E., M.A., F.R.S. University Museum, Oxford.
1889. *MARSHALL, ALFRED, M.A., LL.D., D.Sc. (Pres. F, 1890.) Balliol Croft, Madingley-road, Cambridge.
1904. ‡Marshall, F. H. A. University of Edinburgh.
1905. §Marshall, G. A. K. 6 Chester-place, Hyde Park-square, W.
1892. §MARSHALL, HUGH, D.Sc., F.R.S., F.R.S.E., Professor of Chemistry in University College, Dundee.
1901. ‡Marshall, Robert. 97 Wellington-street, Glasgow.
1886. *MARSHALL, WILLIAM BAYLEY, M.Inst.C.E. Imperial Hotel, Malvern.
1907. ‡Marston, Robert. 14 Ashleigh-road, Leicester.
1899. §Martin, Miss A. M. Park View, 32 Bayham-road, Sevenoaks.
1905. ‡Martin, John. P.O. Box 217, Germiston, Transvaal.
1884. §Martin, N. H., J.P., F.R.S.E., F.L.S. Ravenswood, Low Fell, Gateshead.
1889. *Martin, Thomas Henry, Assoc.M.Inst.C.E. Windermere, Mount Pleasant-road, Hastings.
1905. ‡Marwick, J. S. P.O. Box 1166, Johannesburg.
1905. ‡Marx, Mrs. Charles. Shabana, Robinson-street, Belgravia, South Africa.
1907. ‡Masefield, J. R. B., M.A. Rosehill, Cheadle, Staffordshire.
1847. ‡MASKELYNE, NEVIL STORY, M.A., D.Sc., F.R.S., F.G.S. (Council, 1874–80). Basset Down House, Swindon.
1905. *Mason, Justice A. W. Supreme Court, Pretoria.
1893. *Mason, Thomas. Enderleigh, Alexandra Park, Nottingham.
1891. *Massey, William H., M.Inst.C.E. Twyford, R.S.O., Berkshire.
1885. ‡Masson, David Orme, D.Sc., F.R.S., Professor of Chemistry in the University of Melbourne.
1910. §Masson, Irvine, M.Sc. The University, Melbourne.
1905. §Massy, Miss Mary. York House, Teignmouth, Devon.
1901. *Mather, G. R. Boxlea, Wellingborough.
1910. *Mather, Thomas, F.R.S., Professor of Electrical Engineering in the City and Guilds of London Institute, Exhibition-road, S.W.
1887. *Mather, Right Hon. Sir William, M.Inst.C.E. Salford Iron Works, Manchester.
1909. ‡Mathers, Mr. Justice. 16 Edmonton-street, Winnipeg, Canada.
1908. ‡Matheson, Sir R. E., LL.D. Charlemont House, Rutland-square, Dublin.
1905. ‡Mathew, Alfred Harfield. P.O. Box 242, Cape Town.
1894. ‡MATHEWS, G. B., M.A., F.R.S. 10 Menai View, Bangor, North Wales.
1902. ‡Matley, C. A., D.Sc. 7 Morningside-terrace, Edinburgh.
1904. ‡Matthews, D. J. The Laboratory, Citadel Hill, Plymouth.
1905. ‡Matthews, J. Wright, M.D. P.O. Box 437, Johannesburg.
1899. *Maufe, Herbert B., B.A., F.G.S. Geological Survey Office, 33 George-square, Edinburgh.
1893. ‡Mavor, Professor James. University of Toronto, Canada.
1865. *MAW, GEORGE, F.L.S., F.G.S., F.S.A. Benthall, Kenley, Surrey.
1894. §Maxim, Sir Hiram S. Thurlow Park, Norwood-road, West Norwood, S.E.

Year of Election.

1903. ‡*Maxwell, J. M. 37 Ash-street, Southport.*
1905. §Maylard, A. Ernest. 12 Blythswood-square, Glasgow.
1905. ‡Maylard, Mrs. 12 Blythswood-square, Glasgow.
1878. *Mayne, Thomas. 19 Lord Edward-street, Dublin.
1904. ‡Mayo, Rev. J., LL.D. 6 Warkworth-terrace, Cambridge.
1905. ‡Mearns, J. Herbert, M.D. Edenville, 10 Oxford-road, Observatory, Cape Town.
1879. §Meiklejohn, John W. S., M.D. 105 Holland-road, W.
1905. ‡Mein, W. W. P.O. Box 1145, Johannesburg.
1881. *MELDOLA, RAPHAEL, F.R.S., F.R.A.S., F.C.S., F.I.C. (Pres. B, 1895; Council, 1892–99), Professor of Chemistry in the Finsbury Technical College, City and Guilds of London Institute. 6 Brunswick-square, W.C.
1908. ‡Meldrum, A. N., D.Sc. Chemical Department, The University, Manchester.
1883. ‡Mellis, Rev. James. 23 Part-street, Southport.
1879. *Mellish, Henry. Hodsock Priory, Worksop.
1866. ‡MELLO, Rev. J. M., M.A., F.G.S. Cliff Hill, Warwick.
1881. §Melrose, James. Clifton Croft, York.
1905. *Melvill, E. H. V., F.G.S., F.R.G.S. P.O. Box 719, Johannesburg.
1909. ‡Menzies, Rev. James, M.D. Hwaichingfu, Honan, China.
1905. ‡Meredith, H. O., Professor of Economics in Queen's University, Belfast.
1908. ‡MEREDITH, Sir JAMES CREED, LL.D. Royal University of Ireland, Dublin.
1879. ‡MERIVALE, JOHN HERMAN, M.A. (Local Sec. 1889.) Togston Hall, Acklington.
1899. *Merrett, William H., F.I.C. Hatherley, Grosvenor-road, Wallington, Surrey.
1905. ‡Merriman, Right Hon. John X. Schoongezicht, Stellenbosch, Cape Colony.
1899. ‡Merryweather, J. C. 4 Whitehall-court, S.W.
1889. *Merz, John Theodore. The Quarries, Newcastle-upon-Tyne.
1905. ‡Methven, Cathcart W. Club Arcade, Smith-street, Durban.
1896. §Metzler, W. H., Ph.D., Professor of Mathematics in Syracuse University, Syracuse, New York, U.S.A.
1869. ‡MIALL, LOUIS C., D.Sc., F.R.S., F.L.S., F.G.S. (Pres. D, 1897; Pres. L, 1908; Local Sec. 1890.) Norton Way North, Letchworth.
1903. *Micklethwait, Miss Frances M. G. Penhein, Chepstow, Monmouth.
1881. *Middlesbrough, The Right Rev. Richard Lacy, D.D., Bishop of. Bishop's House, Middlesbrough.
1904. ‡Middleton, T. H., M.A. South House, Barton-road, Cambridge.
1894. *MIERS, H. A., M.A., D.Sc., F.R.S., F.G.S. (Pres. C, 1905; Pres. L, 1910), Principal of the University of London. 23 Wetherby-gardens, S.W.
1885. §MILL, HUGH ROBERT, D.Sc., LL.D., F.R.S.E., F.R.G.S. (Pres. E, 1901.) 62 Camden-square, N.W.
1905. ‡Mill, Mrs. H. R. 62 Camden-square, N.W.
1889. *MILLAR, ROBERT COCKBURN. 30 York-place, Edinburgh.
Millar, Thomas, M.A., LL.D., F.R.S.E. Perth.
1909. §Miller, A. P. Vermilion Bay, Ontario, Canada.
1895. ‡Miller, Thomas, M.Inst.C.E. 9 Thoroughfare, Ipswich.
1909. ‡Miller, Professor W. G. Bureau of Mines, Toronto, Canada.
1904. ‡Millis, C. T. Hollydene, Wimbledon Park-road, Wimbledon.
1905. §Mills, Mrs. A. A. Ceylon Villa, Blinco-grove, Cambridge.
1908. §Mills, Miss E. A. Nurney, Glenagarey, Co. Dublin.

Year of Election.

1868. *MILLS, EDMUND J., D.Sc., F.R.S., F.C.S. 64 Twyford-avenue, West Acton, W.
1908. §Mills, Miss Gertrude Isabel. Nurney, Glenagarey, Co. Dublin.
1908. §Mills, John Arthur, M.B. Durham County Asylum, Winterton, Ferryhill.
1908. §Mills, W. H., M.Inst.C.E. Nurney, Glenagarey, Co. Dublin.
1902. ‡Mills, W. Sloan, M.A. Vine Cottage, Donaghmore, Newry.
1907. ‡Milne, A., M.A. University School, Hastings.
1910. §Milne, J. B. Cross Grove House, Totley, near Sheffield.
1910. *Milne, James Robert, D.Sc., F.R.S.E. 11 Melville-crescent, Edinburgh.
1882. *MILNE, JOHN, D.Sc., F.R.S., F.G.S. Shide, Newport, Isle of Wight.
1903. *Milne, R. M. Royal Naval College, Dartmouth, South Devon.
1898. *Milner, S. Roslington, D.Sc. The University, Sheffield.
1908. §Milroy, T. H., M.D., Dunville Professor of Physiology in Queen's College, Belfast.
1907. §Milton, J. H., F.G.S. Harrison House, Crosby, Liverpool.
1880. ‡MINCHIN, G. M., M.A., F.R.S. 149 Banbury-road, Oxford.
1901. *Mitchell, Andrew Acworth. 7 Huntly-gardens, Glasgow.
1901. *Mitchell, G. A. 5 West Regent-street, Glasgow.
1909. ‡Mitchell, J. F. 211 Rupert-street, Winnipeg, Canada.
1905. ‡Mitchell, John. Government School House, Jeppestown, Transvaal.
1885. ‡MITCHELL, P. CHALMERS, M.A., D.Sc., F.R.S., Sec.Z.S. (Council 1906–). Zoological Society, Regent's Park, N.W.
1908. ‡Mitchell, W. M. 2 St. Stephen's Green, Dublin.
1905. *Mitchell, William Edward. Ferreira Deep, Johannesburg.
1895. *Moat, William, M.A. Johnson Hall, Eccleshall, Staffordshire.
1908. ‡Moffat, C. B. 36 Hardwicke-street, Dublin.
1905. ‡Moir, James, D.Sc. Mines Department, Johannesburg.
1905. ‡Moir, Dr. W. Ironside. Care of Dr. McAulay, Cleveland, Transvaal.
1905. ‡Molengraaff, Professor G. A. F. The Technical University of Delft, The Hague.
1883. ‡Mollison, W. L., M.A. Clare College, Cambridge.
1908. ‡Molloy, W. R. J., J.P., M.R.I.A. 78 Kenilworth-square, Rathgar, Co. Dublin.
1900. *MONCKTON, H. W., Treas.L.S., F.G.S. 3 Harcourt-buildings, Temple, E.C.
1905. *MONCRIEFF, Colonel Sir C. SCOTT, G.C.S.I., K.C.M.G., R.E. (Pres. G, 1905.) 11 Cheyne-walk, S.W.
1905. ‡Moncrieff, Lady Scott. 11 Cheyne-walk, S.W.
1891. *Mond, Robert Ludwig, M.A., F.R.S.E., F.G.S. 20 Avenue-road Regent's Park, N.W.
1909. §Moody, A. W., M.D. 432½ Main-street, Winnipeg, Canada.
1909. §MOODY, G. T., D.Sc. Lorne House, Dulwich, S.E.
1908. *Moore, F. W. Royal Botanic Gardens, Glasnevin, Dublin.
1894. ‡Moore, Harold E. Oaklands, The Avenue, Beckenham, Kent.
1908. ‡Moore, Sir John W., M.D. 40 Fitzwilliam-square West, Dublin.
1901. *Moore, Robert T. 142 St. Vincent-street, Glasgow.
1905. §Moore, T. H. Thornhill Villa, Marsh, Huddersfield.
1896. *Mordey, W. M. 82 Victoria-street, S.W.
1901. *Moreno, Francisco P. Paraná 915, Buenos Aires.
1905. *Morgan, Miss Annie. Friedrichstrasse No. 2, Vienna.
1895. ‡MORGAN, C. LLOYD, F.R.S., F.G.S., Professor of Psychology in the University of Bristol.
1902. ‡MORGAN, GILBERT T., D.Sc., F.I.C. Imperial College of Science and Technology, S.W.

Year of Election.

1902. *Morgan, Septimus Vaughan. 37 Harrington-gardens, S.W.
1901. *Morison, James. Perth.
1883. *MORLEY, HENRY FORSTER, M.A., D.Sc., F.C.S. 5 Lyndhurst-road, Hampstead, N.W.
1906. ‡Morrell, H. R. Scarcroft-road, York.
1896. ‡Morrell, R. S. Caius College, Cambridge.
1908. ‡Morris, E. A. Montmorency, M.A., M.R.I.A. Winton House, Cabra, Co. Dublin.
1905. ‡Morris, F., M.B., B.Sc. 18 Hope-street, Cape Town.
1896. *Morris, J. T. 47 Cumberland-mansions, Seymour-place, W.
1880. §Morris, James. 6 Windsor-street, Uplands, Swansea.
1907. ‡Morris, Colonel Sir W. G., K.C.M.G. Care of Messrs. Cox & Co., 16 Charing Cross, W.C.
1899. *MORROW, JOHN, M.Sc., D.Eng. Armstrong College, Newcastle-upon-Tyne.
1909. ‡Morse, Morton F. Wellington-crescent, Winnipeg, Canada.
1865. ‡Mortimer, J. R. St. John's Villas, Driffield.
1886. *Morton, P. F. 15 Ashley-place, Westminster, S.W.
1896. *MORTON, WILLIAM B., M.A., Professor of Natural Philosophy in Queen's University, Belfast.
1908. ‡Moss, Dr. C. E. Botany School, Cambridge.
1876. §Moss, RICHARD JACKSON, F.I.C., M.R.I.A. Royal Dublin Society, and St. Aubyn's, Ballybrack, Co. Dublin.
1892. *Mostyn, S. G., M.A., M.B. 15 Grange-avenue, Harton, near South Shields.
1878. *MOULTON, The Right Hon. Lord Justice, M.A., K.C., F.R.S. 57 Onslow-square, S.W.
1899 §Mowll, Martyn. Chaldercot, Leyburne-road, Dover.
1905. ‡Moylan, Miss V. C. 3 Canning-place, Palace Gate, W.
1905. *Moysey, Miss E. L. Pitcroft, Guildford, Surrey.
1902. §Muir, Arthur H. 2 Wellington-place, Belfast.
1907. *Muir, Professor James. 31 Burnbank-gardens, Glasgow.
1874. ‡MUIR, M. M. PATTISON, M.A. Gonville and Caius College, Cambridge.
1909. ‡Muir, Robert R. Grain Exchange-building, Winnipeg, Canada.
1904. §Muir, William. Rowallan, Newton Stewart, N.B.
1872. *MUIRHEAD, ALEXANDER, D.Sc., F.R.S., F.C.S. 12 Carteret-street, Queen Anne's Gate, Westminster, S.W.
1905. *Muirhead, James M. P., F.R.S.E. Markham's-chambers, St. George's-street, Cape Town.
1876. *Muirhead, Robert Franklin, B.A., D.Sc. 64 Great George-street, Hillhead, Glasgow.
1902. ‡Mullan, James. Castlerock, Co. Derry.
1884. *MÜLLER, HUGO, Ph.D., F.R.S., F.C.S. 13 Park-square East, Regent's Park, N.W.
1905. ‡Mulligan, A. 'Natal Mercury' Office, Durban, Natal.
1908. ‡MULLIGAN, JOHN. (Local Sec. 1908.) Greinan, Adelaide-road, Kingstown, Co. Dublin.
1904. §Mullinger, J. Bass, M.A. 1 Bene't-place, Cambridge.
1898. ‡Mumford, C. E. Cross Roads House, Bouverie-road, Folkestone.
1901. *Munby, Alan E. 28 Martin's-lane, Cannon-street, E.C.
1906. ‡Munby, Frederick J. Whixley, York.
1904. ‡Munro, A. Queens' College, Cambridge.
1909. ‡Munro, George. 188 Roslyn-road, Winnipeg, Canada.
1883. *MUNRO, ROBERT, M.A., M.D., LL.D. (Pres. H, 1893.) Elmbank, Largs, Ayrshire, N.B.
1909. ‡Munson, J. H., K.C. Wellington-crescent, Winnipeg, Canada.

Year of Election.

1909. §Murphy, A. J. Vanguard Manufacturing Co., Dorrington-street, Leeds.
1908. ‡Murphy, Leonard. 156 Richmond-road, Dublin.
1908. ‡MURPHY, WILLIAM M., J.P. Dartry, Dublin.
1905 ‡Murray, Charles F. K., M.D. Kenilworth House, Kenilworth, Cape Colony.
1905. ‡Murray, Dr. F. Londinium, London-road, Sea Point, Cape Town.
1891. ‡MURRAY, G. R. M., F.R.S., F.R.S.E., F.L.S. 32 Market-square, Stonehaven, N.B.
1905. §Murray, Sir James, LL.D., Litt.D. Sunnyside, Oxford.
1905. §Murray, Lady. Sunnyside, Oxford.
1884. ‡MURRAY, Sir JOHN, K.C.B., LL.D., D.Sc., Ph.D., F.R.S., F.R.S.E. (Pres. E, 1899.) Challenger Lodge, Wardie, Edinburgh.
1903. §Murray, Colonel J. D. Rowbottom-square, Wigan.
1909. ‡Murray, W. C. University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
1870. *Muspratt, Edward Knowles. Seaforth Hall, near Liverpool.
1906. ‡Myddelton-Gavey, E. H., M.R.C.S., J.P. Stanton Prior, Meads, Eastbourne.
1902. ‡Myddleton, Alfred. 62 Duncairn-street, Belfast.
1902. *Myers, Charles S., M.A., M.D. Great Shelford, Cambridge.
1909. *Myers, Henry. The Long House, Leatherhead.
1906. ‡Myers, Jesse A. Glengarth, Walker-road, Harrogate.
1890. *MYRES, JOHN L., M.A., F.S.A. (Pres. H, 1909; Council, 1909–), Wykeham Professor of Ancient History in the University of Oxford. 101 Banbury-road, Oxford.

1886. ‡NAGEL, D. H., M.A. (Local Sec. 1894.) Trinity College, Oxford.
1892. *Nairn, Sir Michael B., Bart. Kirkcaldy, N.B.
1890. ‡Nalder, Francis Henry. 34 Queen-street, E.C.
1908. ‡Nally, T. H. Temple Hill, Terenure, Co. Dublin.
1905. ‡Napier, Dr. Francis. 73 Joppe-street, Von Brandis-square, Johannesburg.
1872. ‡NARES, Admiral Sir G. S., K.C.B., R.N., F.R.S., F.R.G.S. 7 The Crescent, Surbiton.
1909. ‡Neild, Frederic, M.D. Mount Pleasant House, Tunbridge Wells.
1883. *Neild, Theodore, M.A. Grange Court, Leominster.
1898. *Nevill, Rev. J. H. N., M.A. The Vicarage, Stoke Gabriel, South Devon.
1866. *Nevill, The Right Rev. Samuel Tarratt, D.D., F.L.S., Bishop of Dunedin, New Zealand.
1889. ‡NEVILLE, F. H., M.A., F.R.S. Sidney College, Cambridge.
1889. *Newall, H. Frank, M.A., F.R.S., F.R.A.S., Professor of Astrophysics in the University of Cambridge. Madingley Rise, Cambridge.
1901. ‡Newman, F. H. Tullie House, Carlisle.
1889. ‡Newstead, A. H. L., B.A. 38 Green-street, Bethnal Green, N.E.
1893. ‡NEWTON, E. T., F.R.S., F.G.S. Florence House, Willow Bridge-road, Canonbury, N.
1908. ‡Nicholls, W. A. 11 Vernham-road, Plumstead, Kent.
1908. ‡Nichols, Albert Russell. 30 Grosvenor-square, Rathmines, Co. Dublin.
1887. ‡Nicholson, John Carr, J.P. Moorfield House, Headingley, Leeds.
1884. ‡NICHOLSON, JOSEPH S., M.A., D.Sc. (Pres. F, 1893), Professor of Political Economy in the University of Edinburgh.

Year of Election.

1908. §Nicholson, J. W. Trinity College, Cambridge.
1908. ‡Nixon, Sir Christopher, Bart., M.D., LL.D., D.L. 2 Merrion-square, Dublin.
1863. *Noble, Sir Andrew, Bart., K.C.B., D.Sc., F.R.S., F.R.A.S., F.C.S. (Pres. G, 1890; Council, 1903–06; Local Sec. 1863.) Elswick Works, and Jesmond Dene House, Newcastle-upon-Tyne.
1863. §Norman, Rev. Canon Alfred Merle, M.A., D.C.L., LL.D., F.R.S., F.L.S. The Red House, Berkhamsted.
1888. ‡Norman, George. 12 Brock-street, Bath.
1883. *Norris, William G. Dale House, Coalbrookdale, R.S.O., Shropshire.
1894. §Notcutt, S. A., LL.M., B.A., B.Sc. (Local Sec. 1895.) Constitution-hill, Ipswich.
1903. ‡Noton, John. 45 Part-street, Southport.
1909. ‡Nugent, F. S. 81 Notre Dame-avenue, Winnipeg, Canada.
1910. §Nunn, T. Percy, M.A., D.Sc. London Day Training College, Southampton-row, W.C.
1908. §Nutting, Sir John, Bart. St. Helen's, Co. Dublin.

1898. *O'Brien, Neville Forth. Fryth, Pyrford, Surrey.
1908. ‡O'Carroll, Joseph, M.D. 43 Merrion-square East, Dublin.
1883. ‡Odgers, William Blake, M.A., LL.D., K.C. 15 Old-square, Lincoln's Inn, W.C.
1910. *Odling, Marmaduke, B.A., F.G.S. 15 Norham-gardens, Oxford.
1858. *Odling, William, M.B., F.R.S., V.P.C.S. (Pres. B, 1864; Council, 1865–70), Waynflete Professor of Chemistry in the University of Oxford. 15 Norham-gardens, Oxford.
1908. §O'Farrell, Thomas A., J.P. 30 Lansdowne-road, Dublin.
1902. ‡Ogden, James Neal. Claremont, Heaton Chapel, Stockport.
1876. ‡Ogilvie, Campbell P. Lawford-place, Manningtree.
1885. ‡Ogilvie, F. Grant, C.B., M.A., B.Sc., F.R.S.E. (Local Sec 1892.) Board of Education, S.W.
1905. *Oke, Alfred William, B.A., LL.M., F.G.S., F.L.S. 32 Denmark-villas, Hove, Brighton.
1905. §Okell, Samuel, F.R.A.S. Overley, Langham-road, Bowdon, Cheshire.
1908. §Oldham, Charles Hubert, B.A., B.L., Professor of Commerce in the National University of Ireland. 5 Victoria-terrace, Rathgar, Dublin.
1892. ‡Oldham, H. Yule, M.A., F.R.G.S., Lecturer in Geography in the University of Cambridge. King's College, Cambridge.
1893. *Oldham, R. D., F.G.S., Geological Survey of India. Care of Messrs. H. S. King & Co., 9 Pall Mall, S.W.
1863. ‡Oliver, Daniel, LL.D., F.R.S., F.L.S., Emeritus Professor of Botany in University College, London. 10 Kew Gardens-road, Kew, Surrey.
1887. ‡Oliver, F. W., D.Sc., F.R.S., F.L.S. (Pres. K, 1906), Professor of Botany in University College, London, W.C.
1889. ‡Oliver, Professor Sir Thomas, M.D. 7 Ellison-place, Newcastle-upon-Tyne.
1882. §Olsen, O. T., D.Sc., F.L.S., F.R.A.S., F.R.G.S. 116 St. Andrew's-terrace, Grimsby.
1880. *Ommanney, Rev. E. A. St. Michael's and All Angels, Portsea, Hants.
1908. ‡O'Neill, Rev. G., M.A. University College, St. Stephen's Green, Dublin.
1902. ‡O'Neill, Henry, M.D. 6 College-square East, Belfast.

Year of Election.

1902. ‡O'Reilly, Patrick Joseph. 7 North Earl-street, Dublin.
1905. ‡O'Riley, J. C. 70 Barnet-street, Gardens, Cape Town.
1884. *Orpen, Rev. T. H., M.A. The Vicarage, Great Shelford, Cambridge.
1901. ‡Orr, Alexander Stewart. 10 Medows-street, Bombay, India.
1905. ‡Orr, Professor John. Transvaal Technical Institute, Johannesburg.
1909. §Orr, John B. Crossacres, Woolton, Liverpool.
1908. *Orr, William. Dungarvan, Co. Waterford.
1904. *Orton, K. J. P., M.A., Ph.D., Professor of Chemistry in University College, Bangor.
1910. §Osborn, T. G. B., B.Sc. The University, Manchester.
1905. ‡Osborn, Philip B. P.O. Box 4181, Johannesburg.
1901. ‡Osborne, W. A., D.Sc. University College, W.C.
1908. ‡O'Shaughnessy, T. L. 64 Fitzwilliam-square, Dublin.
1887. ‡O'Shea, L. T., B.Sc. University College, Sheffield.
1865. *Osler, Henry F. Coppy-hill, Linthurst, near Bromsgrove, Birmingham.
1884. ‡OSLER, WILLIAM, M.D., LL.D., F.R.S., Regius Professor of Medicine in the University of Oxford. 13 Norham-gardens, Oxford.
1881. *Ottewell, Alfred D. 14 Mill Hill-road, Derby.
1896. ‡Oulton, W. Hillside, Gateacre, Liverpool.
1906. ‡Owen, Rev. E. C. St. Peter's School, York.
1903. *Owen, Edwin, M.A. Terra Nova School, Birkdale, Lancashire.
1896. ‡Owen, Peter. The Elms, Capenhurst, Chester.
1910. *Oxley, A. E. Rose Hill View, Kimberworth-road, Rotherham.

1909. ‡Pace, F. W. 388 Wellington-crescent, Winnipeg, Canada.
1908. ‡Pack-Beresford, Denis, M.R.I.A. Fenagh House, Bagenalstown, Ireland.
1906. §Page, Carl D. Wyoming House, Aylesbury, Bucks.
1903. *Page, Miss Ellen Iva. Turret House, Felpham, Sussex.
1883. ‡Page, G. W. Bank House, Fakenham.
1870. *PALGRAVE, Sir ROBERT HARRY INGLIS, F.R.S., F.S.S. (Pres. F, 1883.) Henstead Hall, Wrentham, Suffolk.
1896. ‡Pallis, Alexander. Tatoi, Aigburth-drive, Liverpool.
1878. *Palmer, Joseph Edward. Royal Societies Club, St. James's-street, S.W.
1866. §Palmer, William. Waverley House, Waverley-street, Nottingham.
1880. *Parke, George Henry, F.L.S., F.G.S. Care of W. T. Cooper, Esq., Aysgarth, The Mall, Southgate, N.
1904. ‡PARKER, E. H., M.A. Thorneycreek, Herschel-road, Cambridge.
1905. ‡Parker, Hugh. P.O. Box 200, Pietermaritzburg, Natal.
1905. ‡Parker, John. 37 Hout-street, Cape Town.
1909. §PARKER, M. A., B.Sc., F.C.S. (Local Sec. 1909), Professor of Chemistry in the University of Manitoba, Winnipeg, Canada.
1891. ‡PARKER, WILLIAM NEWTON, Ph.D., F.Z.S., Professor of Biology in University College, Cardiff.
1905. *Parkes, Tom E. P.O. Box 4580, Johannesburg.
1899. *Parkin, John. Blaithwaite, Carlisle.
1905. *Parkin, Thomas. Blaithwaite, Carlisle.
1906. §Parkin, Thomas, M.A., F.L.S., F.Z.S., F.R.G.S. Fairseat, High Wickham, Hastings.
1879. *Parkin, William. The Mount, Sheffield.
1903. §Parry, Joseph, M.Inst.C.E. Woodbury, Waterloo, near Liverpool.

Year of Election.

1908. ‡Parry, W. K., M.Inst.C.E. 6 Charlemont-terrace, Kingstown, Dublin.
1878. ‡PARSONS, Hon. C. A., C.B., M.A., Sc.D., F.R.S., M.Inst.C.E. (Pres. G, 1904.) Holeyn Hall, Wylam-on-Tyne.
1904. ‡Parsons, Professor F. G. St. Thomas's Hospital, S.E.
1905. *Parsons, Hon. Geoffrey L. Northern Counties Club, Newcastle-on-Tyne.
1898. *Partridge, Miss Josephine M. 15 Grosvenor-crescent, S.W.
1887. ‡PATERSON, A. M., M.D., Professor of Anatomy in the University of Liverpool.
1908. ‡Paterson, M., LL.D. 7 Halton-place, Edinburgh.
1909. ‡Paterson, William. Ottawa, Canada.
1897. ‡Paton, D. Noël, M.D. Physiological Laboratory, The University, Glasgow.
1883. *Paton, Rev. Henry, M.A. Airtnoch, 184 Mayfield-road, Edinburgh.
1884. *Paton, Hugh. Box 2400, Montreal, Canada.
1908. §Patten, C. J., M.A., M.D., Sc.D. The University, Sheffield.
1902. ‡Patterson, R. Glenbank, Hollywood, Co. Down.
1874. ‡Patterson, W. H., M.R.I.A. 26 High-street, Belfast
1879. *Patzer, F. R. Clayton Lodge, Newcastle, Staffordshire.
1883. ‡Paul, George. 32 Harlow Moor-drive, Harrogate.
1863. ‡PAVY, FREDERICK WILLIAM, M.D., LL.D., F.R.S. 35 Grosvenor-street, W.
1887. *Paxman, James. Standard Iron Works, Colchester.
1887. *Payne, Miss Edith Annie. Hatchlands, Cuckfield, Hayward's Heath.
1877. *Payne, J. C. Charles, J.P. Albion-place, The Plains, Belfast.
1881. ‡Payne, Mrs. Albion-place, The Plains, Belfast.
1888. *Paynter, J. B. Hendford Manor, Yeovil.
1876. ‡Peace, G. H., M.Inst.C.E. Monton Grange, Eccles, near Manchester.
1906. ‡Peace, Miss Gertrude. 39 Westbourne-road, Sheffield.
1885. ‡PEACH, B. N., F.R.S., F.R.S.E., F.G.S. Geological Survey Office, George-square, Edinburgh.
1886. *Pearce, Mrs. Horace. Collingwood, Manby-road, West Malvern.
1905. ‡Pearse, S. P.O. Box 149, Johannesburg.
1883. ‡Pearson, Arthur A., C.M.G. Hillsborough, Heath-road, Petersfield, Hampshire.
1893. *Pearson, Charles E. Hillcrest, Lowdham, Nottinghamshire.
1898. ‡Pearson, George. Bank-chambers, Baldwin-street, Bristol.
1905. §Pearson, Professor H. H. W., M.A., F.L.S. South African College, Cape Town.
1883. ‡Pearson, Miss Helen E. Oakhurst, Birkdale, Southport.
1906. ‡Pearson, Joseph. The University, Liverpool.
1904. ‡Pearson, Karl, M.A., F.R.S., Professor of Applied Mathematics in University College, London, W.C.
1909. §Pearson, William. Wellington-crescent, Winnipeg, Canada.
Peckitt, Henry. Carlton Husthwaite, Thirsk, Yorkshire.
1855. *PECKOVER, Lord, LL.D., F.S.A., F.L.S., F.R.G.S. Bank House. Wisbech, Cambridgeshire.
1888. ‡Peckover, Miss Alexandrina. Bank House, Wisbech, Cambridgeshire.
1885. ‡Peddie, William, Ph.D., F.R.S.E., Professor of Natural Philosophy in University College, Dundee.
1884. ‡Peebles, W. E. 9 North Frederick-street, Dublin.
1878. *Peek, William. 4 Carlyle-mansions, Brunswick-place, Hove.
1901. *Peel, Hon. William, M.P. 13 King's Bench-walk, Temple, E.C.

Year of Election.

1905. §Peirson, J. Waldie. P.O. Box 561, Johannesburg.
1905. §Pemberton, Gustavus M. P.O. Box 93, Johannesburg.
1887. ‡PENDLEBURY, WILLIAM H., M.A., F.C.S. (Local Sec. 1899.) Woodford House, Mountfields, Shrewsbury.
1894. ‡Pengelly, Miss. Lamorna, Torquay.
1896. ‡Pennant, P. P. Nantlys, St. Asaph.
1898. ‡Percival, Francis W., M.A., F.R.G.S. 1 Chesham-street, S.W.
1908. ‡Percival, Professor John, M.A. University College, Reading.
1905. ‡Péringuey, L., D.Sc., F.Z.S. South African Museum, Cape Town.
1894. ‡PERKIN, A. G., F.R.S., F.R.S.E., F.C.S., F.I.C. 8 Montpelier-terrace, Hyde Park, Leeds.
1902. *Perkin, F. Mollwo, Ph.D. The Firs, Hengrave-road, Honor Oak Park, S.E.
1884. ‡PERKIN, WILLIAM HENRY, LL.D., Ph.D., F.R.S., F.R.S.E. (Pres. B, 1900; Council, 1901-07), Professor of Organic Chemistry in the Victoria University, Manchester. Fairview, Wilbraham-road, Fallowfield, Manchester.
1864. *Perkins, V. R. Wotton-under-Edge, Gloucestershire.
1898. *Perman, E. P., D.Sc. University College, Cardiff.
1909. ‡Perry, Rev. Professor E. Guthrie. 246 Kennedy-street, Winnipeg, Canada.
1874. *PERRY, JOHN, M.E., D.Sc., LL.D., F.R.S. (GENERAL TREASURER, 1904– ; Pres. G, 1902; Council, 1901-04), Professor of Mechanics and Mathematics in the Imperial College of Science and Technology, S.W.
1904. *Pertz, Miss D. F. M. 2 Cranmer-road, Cambridge.
1900. *Petavel, J. E., M.Sc., F.R.S., Professor of Engineering in the University of Manchester.
1901. ‡Pethybridge, G. H. Royal College of Science, Dublin.
1910. *Petrescu, Lieutenant Dimitrie, R.A., B.Eng. Care of Popp, Corabia, Roumania.
1895. ‡PETRIE, W. M. FLINDERS, D.C.L., F.R.S. (Pres. H, 1895), Professor of Egyptology in University College, W.C.
1871. *Peyton, John E. H., F.R.A.S., F.G.S. Vale House, St. Helier's, Jersey.
1863. *PHENÉ, JOHN SAMUEL, LL.D., F.S.A., F.G.S., F.R.G.S. 5 Carlton-terrace, Oakley-street, S.W.
1903. ‡Philip, James C. 20 Westfield-terrace, Aberdeen.
1905. ‡Philip, John W. P.O. Box 215, Johannesburg.
1853. *Philips, Rev. Edward. Hollington, Uttoxeter, Staffordshire.
1877. §Philips, T. Wishart. Elizabeth Lodge, Crescent-road, South Woodford, Essex.
1905. ‡Phillimore, Miss C. M. Shiplake House, Henley-on-Thames.
1899. *Phillips, Charles E. S., F.R.S.E. Castle House, Shooter's Hill, Kent.
1894. ‡Phillips, Staff-Commander E. C. D., R.N., F.R.G.S. 14 Hargreaves-buildings, Chapel-street, Liverpool.
1910. *Phillips, P. P., Ph.D., Professor of Chemistry in the Thomason Engineering College, Rurki, United Provinces, India.
1890. ‡Phillips, R. W., M.A., D.Sc., F.L.S., Professor of Botany in University College, Bangor. 2 Snowdon-villas, Bangor.
1909. *Phillips, Richard. 15 Dogpole, Shrewsbury.
1905. ‡*Phillp, Miss M. E. de R., B.Sc. 12 Crescent-grove, Clapham, S.W.*
1883. *Pickard, Joseph William. Oatlands, Lancaster.
1901. §Pickard, Robert H., D.Sc. Billinge View, Blackburn.
1885. *PICKERING, SPENCER P. U., M.A., F.R.S. Harpenden, Herts.
1884. *Pickett, Thomas E., M.D. Maysville, Mason Co., Kentucky, U.S.A.

Year of Election.

1907. ‡Pickles, A. R., M.A. Todmorden-road, Burnley.
1888. *Pidgeon, W. R. Lynsted Lodge, St. Edmund's-terrace, Regent's Park, N.W.
1865. ‡Pike, L. Owen. 10 Chester-terrace, Regent's Park, N.W.
1896. *Pilkington, A. C. Rocklands, Rainhill, Lancashire.
1905. ‡Pilling, Arnold. Royal Observatory, Cape Town.
1896. *Pilling, William. Rosario, Heene-road, West Worthing.
1905. ‡Pim, Miss Gertrude. Charleville, Blackrock, Co. Dublin.
1908. *Pio, Professor D. A. 14 Leverton-street, Kentish Town, N.W.
1908. ‡Pirrie, The Right Hon. Lord, LL.D., M.Inst.C.E. Downshire House, Belgrave-square, S.W.
1909. ‡Pitblado, Isaac, K.C. 91 Balmoral-place, Winnipeg, Canada.
1893. *Pitt, Walter, M.Inst.C.E. Lansdown Grove Lodge, Bath.
1908. §Pixell, Miss Helen L. M. St. Faith's Vicarage, Stoke Newington, N.
1900. *Platts, Walter. Fairmount, Bingley.
1898. §Plummer, W. E., M.A., F.R.A.S. The Observatory, Bidston, Birkenhead.
1908. ‡Plunkett, Count G. N. National Museum of Science and Art, Dublin.
1908. ‡Plunkett, Colonel G. T., C.B. Belvedere Lodge, Wimbledon, S.W.
1907. *Plunkett, Right Hon. Sir Horace, K.C.V.O., M.A., F.R.S. Kilteragh, Foxrock, Co. Dublin.
1900. *Pocklington, H. Cabourn, M.A., D.Sc., F.R.S. 11 Regent Park-terrace, Leeds.
1904. ‡Pollard, William. 12 Aberdare-gardens, South Hampstead, N.W.
1908. ‡Pollok, James H., D.Sc. 6 St. James's-terrace, Clonshea, Dublin.
1906. *Pontifex, Miss Catherine E. 7 Hurlingham-court, Fulham, S.W.
1907. ‡Pope, Alfred, F.S.A. South Court, Dorchester.
1900. *Pope, W. J., F.R.S., Professor of Chemistry in the University of Cambridge.
1892. ‡Popplewell, W. C., M.Sc., Assoc.M.Inst.C.E. Bowden-lane, Marple, Cheshire.
1901. §Porter, Alfred W., B.Sc. 87 Parliament Hill-mansions, Lissenden-gardens, N.W.
1883. *Porter, Rev. C. T., LL.D., D.D. All Saints' Vicarage, Southport.
1905. §Porter, J. B., Ph.D., M.Inst.C.E., Professor of Mining Engineering in the McGill University, Montreal, Canada.
1905. ‡Porter, Mrs. McGill University, Montreal, Canada.
1883. ‡Potter, M. C., M.A., F.L.S., Professor of Botany in the Armstrong College, Newcastle-upon-Tyne. 13 Highbury, Newcastle-upon-Tyne.
1906. ‡Potter-Kirby, Alderman George. Clifton Lawn, York.
1907. ‡Potts, F. A. University Museum of Zoology, Cambridge.
1908. *Potts, George, Ph.D., M.Sc. Grey University College, Bloemfontein, South Africa.
1886. *Poulton, Edward B., M.A., F.R.S., F.L.S., F.G.S., F.Z.S. (Pres. D, 1896; Council, 1895–1901, 1905–), Professor of Zoology in the University of Oxford. Wykeham House, Banbury-road, Oxford.
1905. ‡Poulton, Mrs. Wykeham House, Banbury-road, Oxford.
1898. *Poulton, Edward Palmer, M.A. Wykeham House, Banbury-road, Oxford.
1905. ‡Poulton, Miss. Wykeham House, Banbury-road, Oxford.
1905. ‡Poulton, Miss M. Wykeham House, Banbury-road, Oxford.
1873. *Powell, Sir Francis S., Bart., F.R.G.S. Horton Old Hall, Yorkshire; and 1 Cambridge-square, W.

Year of Election.

1894. *Powell, Sir Richard Douglas, Bart., M.D. 62 Wimpole-street, Cavendish-square, W.

1887. §Pownall, George H. 20 Birchin-lane, E.C.

1883. ‡POYNTING, J. H., D.Sc., F.R.S. (Pres. A, 1899), Professor of Physics in the University of Birmingham. 10 Ampton-road, Edgbaston, Birmingham.

1908. ‡Praeger, R. Lloyd, B.A., M.R.I.A. Lisnamae, Rathgar, Dublin.

1907. *PRAIN, Lieut.-Col. DAVID, C.I.E., M.B., F.R.S. (Pres. K, 1909; Council, 1907- .) Royal Gardens, Kew.

1884. *Prankerd, A. A., D.C.L. 66 Banbury-road, Oxford.

1906. ‡Pratt, Miss Edith M., D.Sc. The Woodlands, Silverdale, Lancashire.

1869. *PREECE, Sir WILLIAM HENRY, K.C.B., F.R.S., M.Inst.C.E. (Pres. G, 1888; Council, 1888–95, 1896–1902.) Gothic Lodge, Wimbledon Common, S.W.

1888. *Preece, W. Llewellyn. Bryn Helen, Woodborough-road, Putney, S.W.

1904. §Prentice, Mrs. Manning. Thelema, Undercliff-road, Felixstowe.

1892. ‡Prentice, Thomas. Willow Park, Greenock.

1910. §PRESCOTT, R. M. (Local Sec., 1910.) Town Hall, Sheffield.

1906. ‡Pressly, D. L. Coney-street, York.

1889. ‡Preston, Alfred Eley, M.Inst.C.E., F.G.S. 14 The Exchange, Bradford, Yorkshire.

1903. §Price, Edward E. Oaklands, Oaklands-road, Bromley, Kent.

1888. ‡PRICE, L. L. F. R., M.A., F.S.S. (Pres. F, 1895; Council, 1898-1904.) Oriel College, Oxford.

1875. *Price, Rees. 163 Bath-street, Glasgow.

1897. *PRICE, W. A., M.A. 38 Gloucester-road, Teddington.

1908. §Priestley, J. H. University College, Bristol.

1909. *Prince, Professor E. E. Ottawa, Canada.

1905. ‡Prince, James Perrott, M.D. Durban, Natal.

1889. *Pritchard, Eric Law, M.D., M.R.C.S. 70 Fairhazel-gardens, South Hampstead, N.W.

1876. *PRITCHARD, URBAN, M.D., F.R.C.S. 26 Wimpole-street, W.

1881. §Procter, John William. Ashcroft, York.

1884. *Proudfoot, Alexander, M.D. 100 State-street, Chicago, U.S.A.

1879. *Prouse, Oswald Milton, F.G.S. Alvington, Ilfracombe.

1872. *Pryor, M. Robert. Weston Park, Stevenage, Herts.

1867. *Pullar, Sir Robert, M.P., F.R.S.E. Tayside, Perth.

1883. *Pullar, Rufus D., F.C.S. Brahan, Perth.

1903. §Pullen-Burry, Miss. Lyceum Club, 128 Piccadilly, W.

1904. ‡Punnett, R. C., M.A., Professor of Biology in the University of Cambridge. Caius College, Cambridge.

1905. ‡Purcell, W. F., M.A., Ph.D. South African Museum, Cape Town.

1905. ‡Purcell, Mrs. W. F. South African Museum, Cape Town.

1885. ‡PURDIE, THOMAS, B.Sc., Ph.D., F.R.S., Professor of Chemistry in the University of St. Andrews. 14 South-street, St. Andrews, N.B.

1881. ‡Purey-Cust, Very Rev. Arthur Percival, M.A., Dean of York. The Deanery, York.

1884. *Purves, W. Laidlaw. 20 Stratford-place, Oxford-street, W.

1905. ‡Purvis, Mr. P.O. Box 744, Johannesburg.

1860. *Pusey, S. E. B. Bouverie. Pusey House, Faringdon.

1898. *Pye, Miss E. St. Mary's Hall, Rochester.

1883. §Pye-Smith, Arnold. 32 Queen Victoria-street, E.C.

1883. ‡Pye-Smith, Mrs. 32 Queen Victoria-street, E.C.

1868. ‡PYE-SMITH, P. H., M.D., F.R.S. 48 Brook-street, W.; and Guy's Hospital, S.E.

1879. ‡Pye-Smith, R. J. 350 Glossop-road, Sheffield.

Year of Election.

1893. ‡Quick, James. 22 Bouverie-road West, Folkestone.
1906. *Quiggin, Mrs. A. Hingston. 88 Hartington-grove. Cambridge.

1879. ‡Radford, R. Heber. 15 St. James's-row, Sheffield.
1855. *Radstock, The Right Hon. Lord. Mayfield, Woolston, Southampton.
1887. *Ragdale, John Rowland. The Beeches, Stand, near Manchester.
1905. ‡Raine, Miss. P.O. Box 788, Johannesburg.
1905. ‡Raine, Robert. P.O. Box 1091, Johannesburg.
1898. *Raisin, Miss Catherine A., D.Sc., Bedford College, York-place, Baker-street, W.
1896. *RAMAGE, HUGH, M.A. The Technical Institute, Norwich.
1894. *RAMBAUT, ARTHUR A., M.A., D.Sc., F.R.S., F.R.A.S., M.R.I.A. Radcliffe Observatory, Oxford.
1908. ‡Rambaut, Mrs. Radcliffe Observatory, Oxford.
1876. *RAMSAY, Sir WILLIAM, K.C.B., Ph.D., D.Sc., F.R.S. (PRESIDENT ELECT; Pres. B, 1897; Council, 1891–98), Professor of Chemistry in University College, London. 19 Chester-terrace Regent's Park, N.W.
1883. ‡Ramsay, Lady. 19 Chester-terrace, Regent's Park, N.W.
1869. *Rance, H. W. Henniker, LL.D. 10 Castletown-road, W.
1907. ‡Rankine, A. O. 21 Drayton-road, West Ealing, W.
1868. *Ransom, Edwin, F.R.G.S. 24 Ashburnham-road, Bedford.
1861. ‡RANSOME, ARTHUR, M.A., M.D., F.R.S. (Local Sec. 1861.) 137 Church-street, Chelsea, S.W.
1903. §Rastall, R. H. Christ's College, Cambridge.
1892. *Rathbone, Miss May. Backwood, Neston, Cheshire.
1874. ‡RAVENSTEIN, E. G., F.R.G.S., F.S.S. (Pres. E, 1891.) 2 York-mansions, Battersea Park, S.W.
1908. *Raworth, Alexander. Fairholm, Uppingham-road, Leicester.
1905. ‡Rawson, Colonel Herbert E., R.E. Army Headquarters, Pretoria.
1868. *RAYLEIGH, The Right Hon. Lord, O.M., M.A., D.C.L., LL.D., F.R.S., F.R.A.S., F.R.G.S. (PRESIDENT, 1884; TRUSTEE, 1883– ; Pres. A, 1882; Council, 1878–83), Professor of Natural Philosophy in the Royal Institution, London. Terling Place, Witham, Essex.
1883. *Rayne, Charles A., M.D., M.R.C.S. St. Mary's Gate, Lancaster.
1897. *Rayner, Edwin Hartree, M.A. 40 Gloucester-road, Teddington, Middlesex.
1907. §Rea, Carleton, B.C.L. 34 Foregate-street, Worcester.
1896. *READ, CHARLES H., LL.D., F.S.A. (Pres. H, 1899.) British Museum, W.C.
1902. ‡Reade, R. H. Wilmount, Dunmurry.
1884. §Readman, J. B., D.Sc., F.R.S.E. Staffield Hall, Kirkoswald, R.S.O., Cumberland.
1852. *REDFERN, Professor PETER, M.D. (Pres. D, 1874.) Templepatrick House, Donaghadee, Co. Down.
1890. *Redwood, Sir Boverton, F.R.S.E., F.C.S. Wadham Lodge, Wadham-gardens, N.W.
1908. ‡Reed, Sir Andrew, K.C.B., C.V.O., LL.D. 23 Fitzwilliam-square, Dublin.
1905. §Reed, J. Howard, F.R.G.S. 16 St. Mary's Parsonage, Manchester.
1891. *Reed, Thomas A. Bute Docks, Cardiff.
1894. *Rees, Edmund S. G. Dunscar, Oaken, near Wolverhampton.
1891. *Rees, I. Treharne, M.Inst.C.E. Blaenypant, near Newport, Monmouthshire.
1903. §Reeves, E. A., F.R.G.S. 1 Savile-row, W.

Year of Election.

1906. *Reichel, Sir H. R., LL.D., Principal of University College, Bangor. Penrallt, Bangor, North Wales.
1910. *Reid, Alfred, M.B., M.R.C.S. Kuala Lumpur, Selangor.
1901. *Reid, Andrew T. 10 Woodside-terrace, Glasgow.
1904. ‡Reid, Arthur H. 30 Welbeck-street, W.
1881. §Reid, Arthur S., M.A., F.G.S. Trinity College, Glenalmond, N.B.
1883. *REID, CLEMENT, F.R.S., F.L.S., F.G.S. 28 Jermyn-street, S.W.
1903. *Reid, Mrs. E. M., B.Sc. 7 St. James's-mansions, West End-lane, N.W.
1892. ‡REID, E. WAYMOUTH, B.A., M.B., F.R.S., Professor of Physiology in University College, Dundee.
1908. §REID, GEORGE ARCHDALL, M.B., C.M., F.R.S.E. 9 Victoria-road South, Southsea.
1901. *Reid, Hugh. Belmont, Springburn, Glasgow.
1901. ‡Reid, John. 7 Park-terrace, Glasgow.
1909. ‡Reid, John Young. 329 Wellington-crescent, Winnipeg, Canada.
1904. ‡Reid, P. J. Moor Cottage, Nunthorpe, R.S.O., Yorkshire.
1897. ‡Reid, T. Whitehead, M.D. St. George's House, Canterbury.
1887. *Reid, Walter Francis. Fieldside, Addlestone, Surrey.
1875. ‡REINOLD, A. W., M.A., F.R.S. (Council, 1890–95). 9 Vanbrugh Park-road, Blackheath, S.E.
1894. ‡Rendall, Rev. G. H., M.A., Litt.D. Charterhouse, Godalming.
1891. *Rendell, Rev. James Robson, B.A. Whinside, Whalley-road, Accrington.
1903. *RENDLE, Dr. A. B., M.A., F.R.S., F.L.S. 28 Holmbush-road, Putney, S.W.
1889. *Rennie, George B. 20 Lowndes-street, S.W.
1906. ‡Rennie, John, D.Sc. Natural History Department, University of Aberdeen.
1905. *Renton, James Hall. Rowfold Grange, Billinghurst, Sussex.
1905. ‡Reunert, Clive. Windybrow, Johannesburg.
1905. ‡Reunert, John. Windybrow, Johannesburg.
1904. ‡REUNERT, THEODORE, M.Inst.C.E. P.O. Box 92, Johannesburg.
1905. §Reyersbach, Louis. Care of Messrs. Wernher, Beit, & Co., 1 London Wall-buildings, E.C.
1883. *Reynolds, A. H. 271 Lord-street, Southport.
1871. ‡REYNOLDS, JAMES EMERSON, M.D., D.Sc., F.R.S., F.C.S., M.R.I.A. (Pres. B, 1893; Council, 1893–99.) 3 Inverness-gardens, W.
1900. *Reynolds, Miss K. M. 8 Darnley-road, Notting Hill, W.
1870. *REYNOLDS, OSBORNE, M.A., LL.D., F.R.S., M.Inst.C.E. (Pres. G, 1887.) St. Decuman's, Watchet, Somerset.
1906. ‡Reynolds, S. H., M.A., Professor of Geology and Zoology in the University of Bristol.
1907. §Reynolds, W. Birstall Holt, near Leicester.
1877. *Rhodes, John. 360 Blackburn-road, Accrington, Lancashire.
1899. *RHYS, Professor Sir JOHN, D.Sc. (Pres. H, 1900.) Jesus College, Oxford.
1877. *Riccardi, Dr. Paul, Secretary of the Society of Naturalists. Riva Muro 14, Modena, Italy.
1905. §Rich, Miss Florence, M.A. Granville School, Granville-road, Leicester.
1906. ‡Richards, Rev. A. W. 12 Bootham-terrace, York.
1869. *Richardson, Charles. 3 Cholmley-villas, Long Ditton, Surrey.
1889. ‡Richardson, Hugh, M.A. 12 St. Mary's, York.
1884. *Richardson, J. Clarke. Derwen Fawr, Swansea.

Year of
Election.

1896. *Richardson, Nelson Moore, B.A., F.E.S. Montevideo, Chickerell, near Weymouth.
1901. *Richardson, Professor Owen Willans. 25 Bank-street, Princetown, N.J., U.S.A.
1876. §Richardson, William Haden. City Glass Works, Glasgow.
1883. *Rideal, Samuel, D.Sc., F.C.S. 28 Victoria-street, S.W.
1902. §Ridgeway, William, M.A., D.Litt., F.B.A. (Pres. H, 1908), Professor of Archæology in the University of Cambridge. Flendyshe, Fen Ditton, Cambridge.
1894. ‡Ridley, E. P., F.G.S. (Local Sec. 1895.) Burwood, Westerfield-road, Ipswich.
1881. *Rigg, Arthur. 150 Blomfield-terrace, W.
1883. *Rigg, Edward, I.S.O., M.A. Royal Mint, E.
1910. §Ripper, William, Professor of Engineering in the University of Sheffield.
1892. ‡Rintoul, D., M.A. Clifton College, Bristol.
1905. ‡Ritchie, Professor W., M.A. South African College, Cape Town.
1903. *Rivers, W. H. R., M.D., F.R.S. St. John's College, Cambridge.
1908. *Roaf, Herbert E., M.D., D.Sc. Physiological Department, The University, Liverpool.
1898. *Robb, Alfred A. Lisnabreeny House, Belfast.
1902. *Roberts, Bruno. 30 St. George's-square, Regent's Park, N.W.
1887. *Roberts, Evan. 30 St. George's-square, Regent's Park, N.W.
1881. ‡Roberts, R. D., M.A., D.Sc., F.G.S. University of London, South Kensington, S.W.
1896. ‡Roberts, Thomas J. Ingleside, Park-road, Huyton, near Liverpool.
1897. §Robertson, Sir George S., K.C.S.I. (Pres. E, 1900.) 1 Pump-court, Temple, E.C.
1905. ‡Robertson, Dr. G. W. Office of the Medical Officer of Health, Cape Town.
1897. §Robertson, Professor J. W., C.M.G., LL.D. The Macdonald College, St. Anne de Bellevue, Quebec, Canada.
1901. *Robertson, Robert, B.Sc., M.Inst.C.E. 154 West George-street, Glasgow.
1905. ‡Robertson, Professor T. E. Transvaal Technical Institute, Johannesburg.
1898. ‡Robinson, Charles E., M.Inst.C.E. Holne Cross, Ashburton, South Devon.
1909. ‡Robinson, E. M. 381 Main-street, Winnipeg, Canada.
1903. ‡Robinson, G. H. 1 Weld-road, Southport.
1905. ‡Robinson, Harry. Duncan's-chambers, Shortmarket-street, Cape Town.
1902. ‡Robinson, Herbert C. Holmfield, Aigburth, Liverpool.
1906. ‡Robinson, H. H., M.A., F.I.C. 75 Finborough-road, S.W.
1902. ‡Robinson, James, M.A., F.R.G.S. Dulwich College, Dulwich, S.E.
1888. ‡Robinson, John, M.Inst.C.E. 8 Vicarage-terrace, Kendal.
1908. *Robinson, John Gorges. Cragdale, Settle, Yorkshire.
1910. §Robinson, John Hargreaves. Cable Ship 'Norseman,' Western Telegraph Co., Caixa no Correu No. 117, Pernambuco, Brazil.
1895. *Robinson, Joseph Johnson. 8 Trafalgar-road, Birkdale, Southport.
1905. ‡Robinson, Dr. Leland. 6 Victoria-walk, Woodstock, Cape Town.
1899. *Robinson, Mark, M.Inst.C.E. Parliament-chambers, Great Smith-street, S.W.
1875. *Robinson, Robert, M.Inst.C.E. Beechwood, Darlington.
1908. ‡Robinson, Robert. Field House, Chesterfield.
1904. ‡Robinson, Theodore R. 25 Campden Hill-gardens, W.
1909. ‡Robinson, Captain W. 264 Roslyn-road, Winnipeg, Canada.

Year of Election.

1909. ‡Robinson, Mrs. W. 264 Roslyn-road, Winnipeg, Canada.
1904. ‡Robinson, W. H. Kendrick House, Victoria-road, Penarth.
1870. *Robson, E. R. Palace Chambers, 9 Bridge-street, Westminster, S.W.
1906. ‡Robson, J. Nalton. The Villa, Hull-road, York.
1872. *Robson, William. 12 Albert-terrace, Edinburgh.
1885. *Rodger, Edward. 1 Clairmont-gardens, Glasgow.
1885. *Rodriguez, Epifanio. New Adelphi Chambers, 6 Robert-street, Adelphi, W.C.
1905. ‡Roebuck, William Denison. 259 Hyde Park-road, Leeds.
1907. ‡Roechling, H. Alfred, M.Inst.C.E. 39 Victoria-street, S.W.
1908. §Rogers, A. G. L. Board of Agriculture and Fisheries, 8 Whitehall-place, S.W.
1905. §Rogers, A. W., M.A., F.G.S. South African Museum, Cape Town.
1898. ‡Rogers, Bertram, M.D. (Local Sec. 1898.) 11 York-place, Clifton, Bristol.
1907. ‡Rogers, John D. 85 St. George's-square, S.W.
1890. *Rogers, L. J., M.A., Professor of Mathematics in the University of Leeds. 15 Regent Park-avenue, Leeds.
1906. §Rogers, Reginald A. P. Trinity College, Dublin.
1909. ‡Rogers, Hon. Robert. Roslyn-road, Winnipeg, Canada.
1884. *Rogers, Walter. Lamorva, Falmouth.
1876. ‡Rollit, Sir A. K., B.A., LL.D., D.C.L., F.R.A.S., Hon. Fellow K.C.L. 45 Belgrave-square, S.W.
1905. ‡Rooth, Edward. Pretoria.
1855. *Roscoe, The Right Hon. Sir Henry Enfield, B.A., Ph.D., LL.D., D.C.L., F.R.S. (President, 1887; Pres. B, 1870, 1884; Council, 1874–81; Local Sec. 1861.) 10 Bramham-gardens, S.W.
1905. ‡Rose, Miss G. 45 De Pary's-avenue, Bedford.
1905. ‡Rose, Miss G. Mabel. Ashley Lodge, Oxford.
1883. *Rose, J. Holland, Litt.D. Ethandune, Parkside-gardens, Wimbledon, S.W.
1905. ‡Rose, John G. Government Analytical Laboratory, Cape Town.
1894. *Rose, T. K., D.Sc., Chemist and Assayer to the Royal Mint. 6 Royal Mint, E.
1905. *Rosedale, Rev. H. G., D.D., F.S.A. 36 Richmond-mansions, Earl's Court, S.W.
1905. *Rosedale, Rev. W. E., M.A. Willenhall, Staffordshire.
1905. ‡Rosen, Jacob. 1 Hopkins-street, Yeoville, Transvaal.
1905. ‡Rosen, Julius. Clifton Grange, Jarvie-street, Jeppestown, Transvaal.
1900. ‡Rosenhain, Walter, B.A. Park View, Park-road, Teddington.
1909. ‡Ross, D. A. 116 Wellington-crescent, Winnipeg, Canada.
1859. *Ross, Rev. James Coulman. Wadworth Hall, Doncaster.
1908. ‡Ross, Sir John, of Bladensburg, K.C.B. Rostrevor House, Rostrevor, Co. Down.
1902. ‡Ross, John Callender. 46 Holland-street, Campden-hill, W.
1901. ‡Ross, Colonel Ronald, C.B., F.R.S., Professor of Tropical Medicine and Parasitology in the University of Liverpool. The University, Liverpool.
1891. *Roth, H. Ling. Briarfield, Shibden, Halifax, Yorkshire.
1905. ‡Rothkugel, R. Care of Messrs. D. Isaacs & Co., Cape Town.
1901. *Rottenburg, Paul, LL.D. Care of Messrs. Leister, Bock, & Co., Glasgow.
1899. *Round, J. C., M.R.C.S. 19 Crescent-road, Sydenham Hill, S.E.
1909. ‡Rounthwaite, C. H. E. Engineer's Office, Grand Trunk Pacific Railway of Canada, Winnipeg.
1884. *Rouse, M. L. Hollybank, Hayne-road, Beckenham

Year of Election.

1905. §Rousselet, Charles F. 2 Pembridge-crescent, Bayswater, W.
1903. *Rowe, Arthur W., M.B., F.G.S. 2 Price's-avenue, Margate.
1890. ‡Rowley, Walter, M.Inst.C.E., F.S.A. Alderhill, Meanwood, Leeds.
1881. *Rowntree, Joseph. 38 St. Mary's, York.
1910. §Rowse, Arthur A., B.Sc. Engineering Laboratory, Cambridge.
1875. *RÜCKER, Sir ARTHUR W., M.A., D.Sc., F.R.S. (PRESIDENT, 1901; TRUSTEE, 1898– ; GENERAL TREASURER, 1891–98; Pres. A, 1894; Council, 1888–91.) Everington House, Newbury, Berkshire.
1869. §RUDLER, F. W., I.S.O., F.G.S. Ethel Villa, Tatsfield, Westerham.
1901. *Rudorf, C. C. G., Ph.D., B.Sc. Ivor, Cranley-gardens, Muswell Hill, N.
1905. *Ruffer, Marc Armand, C.M.G., M.A., M.D., B.Sc. Quarantine International Board, Alexandria.
1905. ‡Ruffer, Mrs. Alexandria.
1904. ‡Ruhemann, Dr. S. 3 Selwyn-gardens, Cambridge.
1909. ‡Rumball, Rev. M. C., B.A. Morden, Manitoba, Canada.
1896. *Rundell, T. W., F.R.Met.Soc. 3 Fenwick-street, Liverpool.
1904. ‡Russell, E. J., D.Sc. Rothamsted Experimental Station, Harpenden, Herts.
1875. *Russell, The Hon. F. A. R. Steep, Petersfield.
Russell, John. 39 Mountjoy-square, Dublin.
1883. *Russell, J. W. 28 Staverton-road, Oxford.
1852. *Russell, Norman Scott. Arts Club, Dover-street, W.
1908. ‡Russell, Robert. Arduagremia, Haddon-road, Dublin.
1908. ‡RUSSELL, Right Hon. T. W., M.P. Olney, Terenure, Co. Dublin.
1886. ‡Rust, Arthur. Eversleigh, Leicester.
1909. *Rutherford, Alexander Cameron. Strathcona, Alberta, Canada.
1907. §RUTHERFORD, ERNEST, M.A., D.Sc., F.R.S. (Pres. A, 1909), Professor of Physics in the University of Manchester.
1909. ‡Ruttan, Colonel H. N. Armstrong's Point, Winnipeg, Canada.
1908. ‡Ryan, Hugh, D.Sc. Omdurman, Orwell Park, Rathgar, Dublin.
1905. ‡Ryan, Pierce. Rosebank House, Rosebank, Cape Town.
1909. ‡Ryan, Thomas. Assiniboine-avenue, Winnipeg, Canada.
1906. *RYMER, Sir JOSEPH SYKES. The Mount, York.

1903. ‡SADLER, M. E., LL.D. (Pres. L, 1906). Professor of Education in the Victoria University, Manchester. Eastwood, Weybridge.
1883. ‡Sadler, Robert. 7 Lulworth-road, Birkdale, Southport.
1871. ‡Sadler, Samuel Champernowne. Church House, Westminster, S.W.
1903. ‡Sagar, J. The Poplars, Savile Park, Halifax.
1873. *Salomons, Sir David, Bart., F.G.S. Broomhill, Tunbridge Wells.
1904. §SALTER, A. E., D.Sc., F.G.S. 12 Clifton-road, Brockley, S.E.
1901. ‡Samuel, John S., J.P., F.R.S.E. City Chambers, Glasgow.
1907. *Sand, Dr. Henry J. S. University College, Nottingham.
1907. ‡Sandars, Miss Cora B. Parkholme, Elm Park-gardens, S.W.
Sandes, Thomas, A.B. Sallow Glin, Tarbert, Co. Kerry.
1896. §Saner, John Arthur, M.Inst.C.E. Highfield, Northwich.
1896. ‡Saner, Mrs. Highfield, Northwich.
1903. ‡Sankey, Captain H. R., R.E., M.Inst.C.E. Palace-chambers, 9 Bridge-street, S.W.
1886. ‡Sankey, Percy E. 44 Russell-square, W.C.
1905. ‡Sargant, E. B. Quarry Hill, Reigate.
1896. *Sargant, Miss Ethel. Quarry Hill, Reigate.

Year of Election.

1905. ‡Sargent, Miss Helen A., B.A. Huguenot College, Wellington, Cape Colony.
1907. §Sargent, H. C. Ambergate, near Derby.
1886. ‡Saundby, Robert, M.D. 83A Edmund-street, Birmingham.
1900. *SAUNDER, S. A. Fir Holt, Crowthorne, Berks.
1903. *Saunders, Miss E. R. Newnham College, Cambridge.
1901. ‡Sawers, W. D. 1 Athole Gardens-place, Glasgow.
1887. §SAYCE, Rev. A. H., M.A., D.D. (Pres. H, 1887), Professor of Assyriology in the University of Oxford. Queen's College, Oxford.
1906. ‡Sayer, Dr. Ettie. 35 Upper Brook-street, W.
1883. *Scarborough, George. Whinney Field, Halifax, Yorkshire.
1903. §SCARISBRICK, Sir CHARLES, J.P. Scarisbrick Lodge, Southport.
1903. ‡Scarisbrick, Lady. Scarisbrick Lodge, Southport.
1879. *SCHÄFER, E. A., LL.D., D.Sc., F.R.S., M.R.C.S. (GENERAL SECRETARY, 1895-1900; Pres. I, 1894; Council, 1887-93), Professor of Physiology in the University of Edinburgh.
1888. *SCHARFF, ROBERT F., Ph.D., B.Sc., Keeper of the Natural History Department, National Museum, Dublin.
1880. *Schemmann, Louis Carl. Neueberg 12, Hamburg.
1905. ‡Schonland, S., Ph.D. Albany Museum, Grahamstown, Cape Colony.
1908. §Schrödter, Dr. E. 3-5 Jacobistrasse, Düsseldorf, Germany.
1873. *SCHUSTER, ARTHUR, Ph.D., F.R.S., F.R.A.S. (Pres. A, 1892; Council, 1887-93.) Kent House, Victoria Park, Manchester.
1905. ‡Sclander, J. E. P.O. Box 465, Cape Town.
1847. *SCLATER, PHILIP LUTLEY, M.A., Ph.D., F.R.S., F.L.S., F.G.S., F.R.G.S., F.Z.S. (GENERAL SECRETARY, 1876-81; Pres. D, 1875; Council, 1864-67, 1872-75.) Odiham Priory, Winchfield.
1883. *SCLATER, W. LUTLEY, M.A., F.Z.S. Odiham Priory, Winchfield.
1905. ‡Sclater, Mrs. W. L. Odiham Priory, Winchfield.
1881. *SCOTT, ALEXANDER, M.A., D.Sc., F.R.S., F.C.S. Royal Institution, Albemarle-street, W.
1878. *Scott, Arthur William, M.A., Professor of Mathematics and Natural Science in St. David's College, Lampeter.
1889. *SCOTT, D. H., M.A., Ph.D., F.R.S., Pres.L.S. (GENERAL SECRETARY, 1900-03; Pres. K, 1896.) East Oakley House, Oakley, Hants; and Athenæum Club, Pall Mall, S.W.
1857. *SCOTT, ROBERT H., M.A., D.Sc., F.R.S., F.R.Met.S. 6 Elm Park-gardens, S.W.
1902. ‡Scott, William R. The University, St. Andrews, Scotland.
1895. ‡Scott-Elliot, Professor G. F., M.A., B.Sc., F.L.S. Newton, Dumfries.
1883. ‡Scrivener, Mrs. Haglis House, Wendover.
1909. ‡Scudamore, Colonel F. W. Chelsworth Hall, Suffolk.
1895. ‡Scull, Miss E. M. L. St. Edmund's, 10 Worsley-road, Hampstead, N.W.
1890. *Searle, G. F. C., M.A., F.R.S. Wyncote, Hills-road, Cambridge.
1880. ‡SEDGWICK, ADAM, M.A., F.R.S. (Pres. D. 1899.) 2 Sumner-place, S.W.
1905. ‡Sedgwick, C. F. Strand-street, Cape Town.
1906. *See, T. J. J., A.M., Ph.D., F.R.A.S., Professor of Mathematics, U.S. Navy. Naval Observatory, Mare Island, California.
1907. §Seligmann, Dr. C. G. 15 York-terrace, Regent's Park, N.W.
1904. ‡Sell, W. J. 19 Lensfield-road, Cambridge.
1909. ‡Sellars, H. Lee. 225 Fifth-avenue, New York, U.S.A.

Year of Election.

1888. *SENIER, ALFRED, M.D., Ph.D., F.C.S., Professor of Chemistry in Queen's College, Galway.
1888. *SENNETT, ALFRED R., A.M.Inst.C.E. Duffield, near Derby.
1870. *Sephton, Rev. J. 90 Huskisson-street, Liverpool.
1905. ‡Serrurier, Louis C. Ashley, Sea Point, Cape Town.
1901. ‡Service, Robert. Janefield Park, Maxwelltown, Dumfries.
1910. §Seton, R. S., B.Sc. The University, Leeds.
1895. *Seton-Karr, H. W. 31 Lingfield-road, Wimbledon, Surrey.
1892. *SEWARD, A. C., M.A., F.R.S., F.G.S. (Pres. K, 1903; Council, 1901–07; Local Sec. 1904), Professor of Botany in the University of Cambridge. Westfield, Huntingdon-road, Cambridge.
1899. §Seymour, Professor Henry J., B.A., F.G.S. University College, Earlsfort-terrace, Dublin.
1891. ‡Shackell, E. W. 191 Newport-road, Cardiff.
1905. *Shackleford, W. C., M.Inst.M.E. County Club, Lancaster.
1904. ‡Shackleton, Lieutenant Sir Ernest H., M.V.O., F.R.G.S. 14 South Learmonth-gardens, Edinburgh.
1902. ‡SHAFTESBURY, The Right Hon. the Earl of, D.L. Belfast Castle, Belfast.
1901. *Shakespear, Mrs. G. A. 21 Woodland-road, Northfield, Worcestershire.
1906. ‡Shann, Frederick. 6 St. Leonard's, York.
1878. ‡SHARP, DAVID, M.A., M.B., F.R.S., F.L.S. Museum of Zoology, Cambridge.
1904. ‡Sharples, George. 181 Great Cheetham-street West, Higher Broughton, Manchester.
1910. §Shaw, J. J. 166 Hill Top, West Bromwich.
1889. *Shaw, Mrs. M. S., B.Sc. Brookhayes, Exmouth.
1883. *SHAW, W. N., M.A., Sc.D., F.R.S. (Pres. A, 1908; Council, 1895–1900, 1904–07.) Meteorological Office, 63 Victoria-street, S.W.
1883. ‡Shaw, Mrs. W. N. 10 Moreton-gardens, South Kensington, S.W.
1904. ‡Shaw-Phillips, Miss. 70 Westbourne-terrace, Hyde Park, W.
1903. ‡Shaw-Phillips, T., J.P. 70 Westbourne terrace, Hyde Park, W.
1905. ‡Shenstone, Miss A. Sutton Hall, Barcombe, Lewes.
1905. ‡Shenstone, Mrs. A. E. G. Sutton Hall, Barcombe, Lewes.
1865. ‡Shenstone, Frederick S. Sutton Hall, Barcombe, Lewes.
1900. §Sheppard, Thomas, F.G.S. The Municipal Museum, Hull.
1908. §Sheppard, W. F., Sc.D., LL.M. Board of Education, Whitehall, S.W.
1905. ‡Sheridan, Dr. Norman. 96 Francis-street, Bellevue, Johannesburg.
1883. ‡Sherlock, David. Rahan Lodge, Tullamore, Dublin.
1883. ‡Sherlock, Mrs. David. Rahan Lodge, Tullamore, Dublin.
1896. ‡SHERRINGTON, C. S., M.D., D.Sc., F.R.S. (Pres. I, 1904; Council, 1907–), Professor of Physiology in the University of Liverpool. 16 Grove-park, Liverpool.
1888. *Shickle, Rev. C. W., M.A., F.S.A. St. John's Hospital, Bath.
1908. *Shickle, Miss Mabel G. M. 9 Cavendish-crescent, Bath.
1902. *Shillington, T. Foulkes, J.P. Dromart, Antrim-road, Belfast.
1883. *Shillitoe, Buxton, F.R.C.S. 29 Sydenham-hill, S.E.
1887. *SHIPLEY, ARTHUR E., M.A., D.Sc., F.R.S. (Pres. D, 1909; Council, 1904–), Master of Christ's College, Cambridge.
1909. ‡Shipley, J. W., B.A. University of Manitoba, Winnipeg, Canada.
1897. ‡SHORE, Dr. LEWIS E. St. John's College, Cambridge.
1882. ‡SHORE, T. W., M.D., B.Sc., Lecturer on Comparative Anatomy at St. Bartholomew's Hospital. 6 Kingswood-road, Upper Norwood, S.E.

Year of Election.

1901. ‡Short, Peter M., B.Sc. 1 Holmdene-avenue, Herne Hill, S.E.
1908. §Shorter, Lewis R., B.Sc. 55 Campden Hill-road, W.
1904. *Shrubsall, F. C., M.A., M.D. 34 Lime-grove, Uxbridge-road, W.
1910. §Shuttleworth, T. E. 5 Park-avenue, Riverdale-road, Sheffield.
1889. ‡Sibley, Walter K., M.A., M.D. The Mansions, 70 Duke-street, W.
1902. ‡Siddons, A. W. Harrow-on-the-Hill, Middlesex.
1883. *Sidebotham, Edward John. Erlesdene, Bowdon, Cheshire.
1877. *Sidebotham, Joseph Watson. Merlewood, Bowdon, Cheshire.
1873. *SIEMENS, ALEXANDER, M.Inst.C.E. Caxton House, Westminster, S.W.
1905. ‡Siemens, Mrs. A. Caxton House, Westminster, S.W.
1903. *Silberrad, Dr. Oswald. Buckhurst Hill, Essex.
1871. *SIMPSON, Sir ALEXANDER R., M.D., Emeritus Professor of Midwifery in the University of Edinburgh. 52 Queen-street, Edinburgh.
1863. ‡Simpson, J. B., F.G.S. Hedgefield House, Blaydon-on-Tyne.
1909. ‡Simpson, Professor J. C. McGill University, Montreal, Canada.
1908. ‡Simpson, J. J., M.A., B.Sc. Zoological Department, Marischal College, Aberdeen.
1901. *Simpson, Professor J. Y., M.A., D.Sc., F.R.S.E. 25 Chester-street, Edinburgh.
1907. §Simpson, Lieut.-Colonel R. J. S., C.M.G. 66 Shooters Hill-road, Blackheath, S.E.
1909. *Simpson, Samuel, B.Sc. 49 Finsbury-pavement, E.C.
1909. ‡Simpson, Sutherland, M.D. Cornell University Medical College, Ithaca, New York, U.S.A.
1894. §Simpson, Thomas, F.R.G.S. Fennymere, Castle Bar, Ealing, W.
1896. *SIMPSON, W., F.G.S. Catteral Hall, Settle, Yorkshire.
1884. *Simpson, Professor W. J. R., C.M.G., M.D. 31 York-terrace, Regent's Park, N.W.
1909. ‡Sinclair, J. D. 77 Spence-street, Winnipeg.
1874. ‡SINCLAIR, Right Hon. THOMAS. (Local Sec. 1874.) Dunedin, Belfast.
1907. *Sircar, Dr. Amrita Lal, L.M.S., F.C.S. 51 Sankaritola, Calcutta.
1905. *SJOGREN, Professor H. Natural History Museum, Stockholm, Sweden.
1902. ‡Skeffington, J. B., M.A., LL.D. Waterford.
1906. ‡Skerry, H. A. St. Paul's-square, York.
1883. ‡Skillicorne, W. N. 9 Queen's-parade, Cheltenham.
1910. §Skinner, J. C. 76 Ivy Park-road, Sheffield.
1898. ‡SKINNER, SIDNEY, M.A. (Local Sec. 1904.) South-Western Polytechnic, Manresa-road, Chelsea, S.W.
1905. *Skyrme, C. G. 28 Norman-road, St. Leonards-on-Sea.
1905. ‡Slater, Dr. H. B. 75 Bree-street, Johannesburg.
1889. §Slater, Matthew B., F.L.S. Malton, Yorkshire.
1887. ‡Small, Evan W., M.A., B.Sc., F.G.S. 48 Kedleston-road, Derby.
1903. *Smallman, Raleigh S. Homeside, Devonshire-place, Eastbourne.
1904. ‡Smart, Edward. Benview, Craigie, Perth, N.B.
1889. *SMART, Professor WILLIAM, LL.D. (Pres. F, 1904.) Nunholme, Dowanhill, Glasgow.
1902. §Smedley, Miss Ida. 36 Russell-square, W.C.
1905. ‡Smith, Miss Adelaide. Huguenot College, Wellington, Cape Colony.
1892. ‡Smith, Alexander, B.Sc., Ph.D., F.R.S.E. Chicago, Illinois, U.S.A.
1908. ‡Smith, Alfred. 30 Merrion-square, Dublin.
1897. ‡Smith, Andrew, Principal of the Veterinary College, Toronto, Canada.

Year of Election.

1901. *Smith, Miss Annie Lorrain. 20 Talgarth-road, West Kensington, W.
1874. *Smith, Benjamin Leigh, F.R.G.S. Oxford and Cambridge Club, Pall Mall, S.W.
1873. ‡Smith, C. Sidney-Sussex College, Cambridge.
1905. ‡Smith, C. H. Fletcher's-chambers, Cape Town.
1910. §Smith, Charles. 11 Winter-street, Sheffield.
1889. *Smith, Professor C. Michie, C.I.E., B.Sc., F.R.S.E., F.R.A.S. The Observatory, Kodaikanal, South India.
1900. §Smith, E. J. Grange House, Westgate Hill, Bradford.
1908. ‡Smith, E. Shrapnell. 7 Rosebery-avenue, E.C.
1886. *Smith, Mrs. Emma. Hencotes House, Hexham.
1901. §Smith, F. B. Care of A. Croxton Smith, Esq., Burlington House, Wandle-road, Upper Tooting, S.W.
1866. *Smith, F. C. Bank, Nottingham.
1897. ‡Smith, G. Elliot, M.D., F.R.S., Professor of Anatomy in the University of Manchester.
1903. *Smith, Professor H. B. Lees, M.A., M.P. The University, Bristol.
1910. §Smith, H. Bompas, M.A. King Edward VII. School, Lytham.
1889. *SMITH, Sir H. LLEWELLYN, K.C.B., M.A., B.Sc., F.S.S. (Pres. F, 1910.) Board of Trade, S.W.
1860. *Smith, Heywood, M.A., M.D. 40 Portland-court, W.
1876. *Smith, J. Guthrie. 5 Kirklee-gardens, Kelvinside, Glasgow.
1902. ‡Smith, J. Lorrain, M.D., F.R.S., Professor of Pathology in the Victoria University, Manchester.
1903. *Smith, James. Pinewood, Crathes, Aberdeen.
1910. §Smith, Samuel. Central Library, Sheffield.
1894. §Smith, T. Walrond. Care of Frank Henderson, Esq., 19 Manor-road, Sidcup, Kent.
1910. §Smith, W. G., B.Sc., Ph.D. College of Agriculture, Edinburgh.
1896. *Smith, Rev. W. Hodson. Newquay, Cornwall.
1885. *Smith, Watson. 34 Upper Park-road, Haverstock Hill, N.W.
1909. ‡Smith, William. 218 Sherbrooke-street, Winnipeg, Canada.
1883. ‡SMITHELLS, ARTHUR, B.Sc., F.R.S. (Pres. B, 1907; Local Sec. 1890), Professor of Chemistry in the University of Leeds.
1906. §Smurthwaite, Thomas E. 134 Mortimer-road, Kensal Rise, N.W.
1905. §Smuts, C. P.O. Box 1088, Johannesburg.
1909. §Smylie, Hugh. 13 Donegall-square North, Belfast.
1908. §Smyly, Sir William J. 58 Merrion-square, Dublin.
1857. *SMYTH, JOHN, M.A., F.C.S., F.R.M.S., M.Inst.C.E.I. Milltown, Banbridge, Ireland.
1908 §Smythe, J. A., Ph.D., D.Sc. 10 Queen's-gardens, Benton, Newcastle-on-Tyne.
1888. *SNAPE, H. LLOYD, D.Sc., Ph.D. Balholm, Lathom-road, Southport.
1905. ‡SODDY, F., M.A., F.R.S. The University, Glasgow.
1905. ‡Sollas, Miss I. B. J., B.Sc. Newnham College, Cambridge.
1879. *SOLLAS, W. J., M.A., Sc.D., F.R.S., F.R.S.E., F.G.S. (Pres. C, 1900; Council, 1900–03), Professor of Geology in the University of Oxford. 173 Woodstock-road, Oxford.
1905 ‡Solomon, R. Stuart. Care of Messrs. R. M. Moss & Co., Cape Town.
1892. *SOMERVAIL, ALEXANDER. The Museum, Torquay.
1900. *SOMERVILLE, W., D.Sc., F.L.S., Sibthorpian Professor of Rural Economy in the University of Oxford. 121 Banbury-road, Oxford.
1910. *Sommerville, Duncan M. Y. 70 Argyle-street, St. Andrews, N.B.
1901. ‡Sorley, Robert. The Firs, Partickhill, Glasgow.

Year of Election.
1903. ‡Soulby, R. M. Sea Holm, Westbourne-road, Birkdale, Lancashire.
1903. ‡Southall, Henry T. The Graig, Ross, Herefordshire.
1865. *Southall, John Tertius. Parkfields, Ross, Herefordshire.
1883. ‡Spanton, William Dunnett, F.R.C.S. Chatterley House, Hanley, Staffordshire.
1909. ‡Sparling, Rev. J. W., D.D. 159 Kennedy-street, Winnipeg, Canada.
1893. *Speak, John. Kirton Grange, Kirton, near Boston.
1910. §Spearman, C. Birnam, Guernsey.
1905. ‡Spencer, Charles Hugh. P.O. Box 2, Maraisburg, Transvaal.
1910. §Spicer, Rev. E. C. The Rectory, Waterstock, Oxford.
1864. *Spicer, Henry, B.A., F.L.S., F.G.S. 14 Aberdeen-park, Highbury, N.
1894. ‡Spiers, A. H. Gresham's School, Holt, Norfolk.
1864. *Spiller, John, F.C.S. 2 St. Mary's-road, Canonbury, N.
1864. *Spottiswoode, W. Hugh, F.C.S. 6 Middle New-street, Fetter-lane, E.C.
1909. ‡Sprague, D. E. 76 Edmonton-street, Winnipeg, Canada.
1854. *Sprague, Thomas Bond, M.A., LL.D., F.R.S.E. 29 Buckingham-terrace, Edinburgh.
1888. *Stacy, J. Sargeant. 164 Shoreditch, E.C.
1903. ‡Stallworthy, Rev. George B. The Manse, Hindhead, Haslemere, Surrey.
1883. *Stanford, Edward, F.R.G.S. 12-14 Long-acre, W.C.
1905. ‡Stanley, Professor George H. Transvaal Technical Institute, Johannesburg.
1883. ‡Stanley, Mrs. Cumberlow, South Norwood, S.E.
1894. *Stansfield, Alfred, D.Sc. McGill University, Montreal, Canada.
1909. §Stansfield, Edgar. Mines Branch, Department of Mines, Ottawa, Canada.
1900. *Stansfield, H., B.Sc. 19 Cawdor-road, Fallowfield, Manchester.
1905. ‡Stanwell, Dr. St. John. P.O. Box 1050, Johannesburg.
1905. ‡Stapleton, Frederick. Control and Audit Office, Cape Town.
1905. **Starkey, A. H.* 24 *Greenhead-road, Huddersfield.*
1899. ‡Starling, E. H., M.D., F.R.S. (Pres. I, 1909), Professor of Physiology in University College, London, W.C.
1898. ‡Stather, J. W., F.G.S. Brookside, Newland Park, Hull.
Staveley, T. K. Ripon, Yorkshire.
1907. §Staynes, Frank. 36-38 Silver-street, Leicester.
1910. §Stead, F. B. 80 St. Mary's-mansions, Paddington, W.
1900. *Stead, J. E., F.R.S. (Pres. B, 1910.) Laboratory and Assay Office, Middlesbrough.
1881. ‡Stead, W. H. Beech-road, Reigate.
1892. *Stebbing, Rev. Thomas R. R., M.A., F.R.S. Ephraim Lodge, The Common, Tunbridge Wells.
1896. *Stebbing, W. P. D., F.G.S. 78a Lexham-gardens, W.
1905. ‡Stebbins, Miss Inez F., B.A. Huguenot College, Wellington, Cape Town.
1908. ‡Steele, Lawrence Edward, M.A., M.R.I.A. 18 Crosthwaite-park East, Kingstown, Co. Dublin.
1909. ‡Steinkopj, Max. 667 Main-street, Winnipeg, Canada.
1905. ‡Stephen, J. M. Invernegie, Sea Point, Cape Colony.
1884. *Stephens, W. Hudson. Low-Ville, Lewis County, New York. U.S.A.
1902. ‡Stephenson, G. Grianan, Glasnevin, Dublin.
1910. *Stephenson, H. K. Banner Cross Hall, Sheffield.
1909. ‡Stethern, G. A. Fort Frances, Ontario, Canada.

Year of Election.

1908 *Steven, Alfred Ingram, M.A., B.Sc. 54 Albert-drive, Pollokshields, Glasgow.
1906. §Stevens, Miss C. O. 11 Woodstock-road, Oxford.
1880. *Stevens, J. Edward, LL.B. Le Mayals, Blackpill, R.S.O.
1900. ‡STEVENS, FREDERICK. (Local Sec. 1900.) Town Clerk's Office, Bradford.
1905. §Stewart, A. F. 127 Isabella-street, Toronto, Canada.
1905. ‡Stewart, Charles. Meteorological Commission, Cape Town.
1909. ‡Stewart, David A., M.D. 407 Pritchard-avenue, Winnipeg, Canada.
1875. *Stewart, James, B.A., F.R.C.P.Ed. Junior Constitutional Club, Piccadilly, W.
1901. *Stewart, John Joseph, M.A., B.Sc. 2 Stow Park-crescent, Newport, Monmouthshire.
1901. *Stewart, Thomas. St. George's-chambers, Cape Town.
1876. ‡STIRLING, WILLIAM, M.D., D.Sc., F.R.S.E., Professor of Physiology in the Victoria University, Manchester.
1904. ‡Stobbs, J. T. Dunelm, Basford Park, Stoke-on-Trent.
1906. *Stobo, Mrs. Annie. Somerset House, Garelochhead, Dumbartonshire, N.B.
1901. *Stobo, Thomas. Somerset House, Garelochhead, Dumbartonshire, N.B.
1865. *Stock, Joseph S. St. Mildred's, Walmer.
1883. *STOCKER, W. N., M.A. Brasenose College, Oxford.
1898. *Stokes, Professor George J., M.A. 5 Fernhurst-villas, College-road, Cork.
1899. *Stone, Rev. F. J. Radley College, Abingdon.
1874. ‡Stone, J. Harris, M.A., F.L.S., F.C.S. 3 Dr. Johnson's-buildings, Temple, E.C.
1905. ‡Stoneman, Miss Bertha, D.Sc. Huguenot College, Wellington, Cape Colony.
1895. *Stoney, Miss Edith A. 30 Chepstow-crescent, W.
1908. *Stoney, Miss Florence A., M.D. 4 Nottingham-place, W.
1878. *Stoney, G. Gerald. Oakley, Heaton-road, Newcastle-upon-Tyne.
1861. *STONEY, GEORGE JOHNSTONE, M.A., D.Sc., F.R.S., M.R.I.A. (Pres. A, 1897.) 30 Chepstow-crescent, W.
1883. ‡Stopes, Mrs. 7 Denning-road, Hampstead, N.W.
1903. *Stopes, Miss Marie, Ph.D., D.Sc. 14 Well-walk, Hampstead, N.W.
1910. §Storey, Gilbert. Lime Grove, Brooklands, near Manchester.
1887. *Storey, H. L. Bailrigg, Lancaster.
1888. *Stothert, Percy K. Woolley Grange, Bradford-on-Avon, Wilts.
1905. *Stott, Clement H., F.G.S. P.O. Box 7, Pietermaritzburg, Natal.
1881. ‡STRAHAN, AUBREY, M.A., F.R.S., F.G.S. (Pres. C, 1904.) Geological Museum, Jermyn-street, S.W.
1905. ‡Strange, Harold F. P.O. Box 2527, Johannesburg.
1908. *Stratton, F. J. M., M.A. Gonville and Caius College, Cambridge.
1906. *Stromeyer, C. E. 9 Mount-street, Albert-square, Manchester.
1883. §Strong, Henry J., M.D. Colonnade House, The Steyne, Worthing.
1898. *Strong, W. M., M.D. 3 Champion-park, Denmark Hill, S.E.
1887. *Stroud, H., M.A., D.Sc., Professor of Physics in the Armstrong College, Newcastle-upon-Tyne.
1887. *STROUD, WILLIAM, D.Sc., Professor of Physics in the University of Leeds. Care of Messrs. Barr & Stroud, Anniesland, Glasgow.
1905. ‡Struben, Mrs. A. P.O. Box 1228, Pretoria.
1876. *Stuart, Charles Maddock, M.A. St. Dunstan's College, Catford, S.E.
1872. *Stuart, Rev. Canon Edward A., M.A. The Precincts, Canterbury.

Year of Election.

1885. ‡Stump, Edward C. Malmesbury, Polefield, Blackley, Manchester.
1909. §Stupart, R. F. Meteorological Service, Toronto, Canada.
1879. *Styring, Robert. Brinkcliffe Tower, Sheffield.
1891. *Sudborough, Professor J. J., Ph.D., D.Sc. University College of Wales, Aberystwyth.
1902. §Sully, H. T. Scottish Widows-buildings, Bristol.
1898. §Sully, T. N. Avalon House, Queen's-road, Weston-super-Mare.
1905. ‡Summer, A. B. Ollersett Booyseux, Transvaal.
1887. *Sumpner, W. E., D.Sc. Technical School, Suffolk-street, Birmingham.
1908. §Sutherland, Alexander. School House, Gersa, Watten, Caithness.
1903. ‡Swallow, Rev. R. D., M.A. Chigwell School, Essex.
1905. ‡Swan, Miss Hilda. Overhill, Warlingham, Surrey.
1881. §SWAN, Sir JOSEPH WILSON, M.A., D.Sc., F.R.S. Overhill, Warlingham, Surrey.
1905. ‡Swan, Miss Mary E. Overhill, Warlingham, Surrey.
1897. ‡Swanston, William, F.G.S. Mount Collyer Factory, Belfast.
1908. ‡Swanzy, Sir Henry R., M.D. 23 Merrion-square, Dublin.
1882. *Swaythling, Lord. 12 Kensington Palace-gardens, W.
1887. §SWINBURNE, JAMES, F.R.S., M.Inst.C.E. 82 Victoria-street, S.W.
1870. *Swinburne, Sir John, Bart. Capheaton Hall, Newcastle-upon-Tyne.
1902. *Sykes, Miss Ella C. Elcombs, Lyndhurst, Hampshire.
1887. *Sykes, George, H., M.A., M.Inst.C.E., F.S.A. Glencoe, 64 Elmbourne-road, Tooting Common, S.W.
1896. *Sykes, Mark L., F.R.M.S. 10 Headingley-avenue, Leeds.
1902. *Sykes, Major P. Molesworth, C.M.G. Elcombs, Lyndhurst, Hampshire.
1906. ‡Sykes, T. P., M.A. 4 Gathorne-street, Great Horton, Bradford.
1905. ‡Symington, C., M.B. Railway Medical Office, De Aar, Cape Colony.
1903. §Symington, Howard W. Brooklands, Market Harborough.
1885. ‡SYMINGTON, JOHNSON, M.D., F.R.S., F.R.S.E. (Pres. H, 1903). Professor of Anatomy in Queen's University, Belfast.
1905. ‡Symmes, H. C. P.O. Box 3902, Johannesburg.
1908. ‡Synnott, Nicholas J. Furness, Naas, Co. Kildare.

1896. ‡Tabor, J. M. Holmwood, Haringey Park, Crouch End, N.
1910. §Tait, John, M.D., D.Sc. 2 Parkside-terrace, Edinburgh.
1904. §Tallack, H. T. Clovelly, Birdhurst-road, South Croydon.
1903. *Tanner, Miss Ellen G. Parkside, Corsham, Wilts.
1890. ‡TANNER, H. W. LLOYD, D.Sc., F.R.S. (Local Sec. 1891.) University College, Cardiff.
1892. *Tansley, Arthur G., M.A., F.L.S. Grantchester, near Cambridge.
1883. *Tapscott, R. Lethbridge, F.R.A.S. 62 Croxteth-road, Liverpool.
1908. ‡TARLETON, FRANCIS A., LL.D. 24 Upper Leeson-street, Dublin.
1861. *Tarratt, Henry W. 2c Oxford and Cambridge-mansions, Hyde Park, W.
1902. ‡Tate, Miss. Rantalard, Whitehouse, Belfast.
1902. ‡*Taylor, Benson. 22 Hayburn-crescent, Partick, Glasgow.*
1908. ‡Taylor, Rev. Campbell, M.A. United Free Church Manse, Wigtown, Scotland.
1887. ‡Taylor, G. H. Holly House, 235 Eccles New-road, Salford.
1898. ‡Taylor, Lieut.-Colonel G. L. Le M. 6 College-lawn, Cheltenham.
1881. *Taylor, H. A. 12 Melbury-road, Kensington, W.
1906. ‡Taylor, H. Dennis. Stancliffe, Mount-villas, York.

Year of
Election.

1884. *Taylor, H. M., M.A., F.R.S. Trinity College, Cambridge.
1882. *Taylor, Herbert Owen, M.D. Oxford-street, Nottingham.
1860. *Taylor, John, M.Inst.C.E. 6 Queen Street-place, E.C.
1906. §Taylor, Miss M. R. Newstead, Blundellsands.
1884. *Taylor, Miss S. Oak House, Shaw, near Oldham.
1895. ‡Taylor, W. A., M.A., F.R.S.E. 3 East Mayfield, Edinburgh.
1894. *Taylor, W. W., M.A. 66 St. John's-road, Oxford.
1903. ‡Taylor, William. 61 Cambridge-road, Southport.
1901. *Teacher, John H., M.B. 32 Kingsborough-gardens, Glasgow.
1858. ‡Teale, Thomas Pridgin, M.A., F.R.S. 38 Cookridge-street, Leeds.
1885. ‡Teall, J. J. H., M.A., F.R.S., F.G.S. (Pres. C, 1893; Council, 1894–1900, 1909–), Director of the Geological Survey of the United Kingdom. The Museum, Jermyn-street, S.W.
1906. *Teape, Rev. W. M., M.A. South Hylton Vicarage, Sunderland.
1910. §Tebb, W. Scott, M.A., M.D. 15 Finsbury-circus, E.C.
1879. ‡Temple, Lieutenant G. T., R.N., F.R.G.S. Solheim, Cumberland Park, Acton, W.
1896. *Terry, Rev. T. R., M.A., F.R.A.S. The Rectory, East Ilsley, Newbury, Berkshire.
1892. *Tesla, Nikola. 45 West 27th-street, New York, U.S.A.
1883. ‡Tetley, C. F. The Brewery, Leeds.
1883. ‡Tetley, Mrs. C. F. The Brewery, Leeds.
1882. *Thane, George Dancer, LL.D., Professor of Anatomy in University College, London, W.C.
1871. ‡Thiselton-Dyer, Sir W. T., K.C.M.G., C.I.E., M.A., B.Sc., Ph.D., LL.D., F.R.S., F.L.S. (Pres. D, 1888; Pres. K, 1895; Council, 1885–89, 1895–1900.) The Ferns, Witcombe, Gloucester.
1906. *Thoday, D. Trinity College, Cambridge.
1906. *Thoday, Mrs. M. G. 25 Halifax-road, Cambridge.
1870. ‡Thom, Colonel Robert Wilson, J.P. Brooklands, Lord-street West, Southport.
1891. *Thomas, Miss Clara. Pencerrig, Builth.
1903. *Thomas, Miss Ethel N., B.Sc. 3 Downe-mansions, Gondar-gardens, West Hampstead, N.W.
1910. §Thomas, H. Hamshaw. Botany School, Cambridge.
1880. *Thomas, Joseph William, F.C.S. Overdale, Shortlands, Kent.
1899. *Thomas, Mrs. J. W. Overdale, Shortlands, Kent.
1902. *Thomas, Miss M. Beatrice. Girton College, Cambridge.
1883. ‡Thomas, Thomas H. 45 The Walk, Cardiff.
1904. *Thomas, William. Bryn-heulog, Thomas Town, Merthyr Tydfil.
1891. *Thompson, Beeby, F.C.S., F.G.S. 67 Victoria-road, Northampton.
1888. *Thompson, Claude M., M.A., D.Sc., Professor of Chemistry in University College, Cardiff. 38 Park-place, Cardiff.
1885. ‡Thompson, D'Arcy W., C.B., B.A., Professor of Zoology in University College, Dundee.
1896. *Thompson, Edward P. Paulsmoss, Whitchurch, Salop.
1907. *Thompson, Edwin. 1 Croxteth-grove, Liverpool.
1883. *Thompson, Francis. Eversley, Haling Park-road, Croydon.
1904. *Thompson, G. R., B.Sc., Professor of Mining in the University of Leeds.
1893. *Thompson, Harry J., M.Inst.C.E., Madras. Care of National Bank of India, 17 Bishopsgate-street Within, E.C.
1883. *Thompson, Henry G., M.D. 86 Lower Addiscombe-road, Croydon.
1905. ‡Thompson, James. P.O. Box 312, Johannesburg.
1909. §Thompson, Miss Mabel. Ashbourne Cottage, Blanford-road, Reigate.

Year of Election.

1876. *Thompson, Richard. Dringcote, The Mount, York.
1876. ‡THOMPSON, SILVANUS PHILLIPS, B.A., D.Sc., F.R.S., F.R.A.S. (Pres. G, 1907; Council, 1897-99, 1910-), Principal and Professor of Physics in the City and Guilds of London Technical College, Leonard-street, Finsbury, E.C.
1883. *Thompson, T. H. Oldfield Lodge, Gray-road, Bowdon, Cheshire.
1896. *THOMPSON, W. H., M.D., D.Sc. (Local Sec. 1908), King's Professor of Institutes of Medicine (Physiology) in Trinity College, Dublin. 14 Hatch-street, Dublin.
1905. ‡*Thompson, William. Parkside, Doncaster-road, Rotherham.*
1894. ‡THOMSON, ARTHUR, M.A., M.D., Professor of Human Anatomy in the University of Oxford. Exeter College, Oxford.
1909. *Thomson, E. 22 Monument-avenue, Swampscott, Mass., U.S.A.
1906. §Thomson, F. Ross, F.G.S. Hensill, Hawkhurst, Kent.
1890. *THOMSON, Professor J. ARTHUR, M.A., F.R.S.E. Castleton House, Old Aberdeen.
1883. ‡THOMSON, Sir J. J., M.A., Sc.D., D.Sc., F.R.S. (PRESIDENT, 1909; Pres. A, 1896; Council, 1893-95), Professor of Experimental Physics in the University of Cambridge. Trinity College, Cambridge.
1901. ‡Thomson, Dr. J. T. Kilpatrick. 148 Norfolk-street, Glasgow.
1889. *Thomson, James, M.A. 22 Wentworth-place, Newcastle-upon-Tyne.
1902. ‡Thomson, James Stuart. 29 Ladysmith-road, Edinburgh.
1891. ‡Thomson, John. Westover, Mount Ephraim-road, Streatham, S.W.
1871. *THOMSON, JOHN MILLAR, LL.D., F.R.S. (Council, 1895-1901), Professor of Chemistry in King's College, London. 9 Campden Hill-gardens, W.
1874. §THOMSON, WILLIAM, F.R.S.E., F.C.S. Royal Institution, Manchester.
1880. §Thomson, William J. Ghyllbank, St. Helens.
1906. ‡Thornely, Miss A. M. M. Oaklands, Langham-road, Bowdon, Cheshire.
1905. *Thornely, Miss L. R. Nunclose, Grassendale, Liverpool.
1898. *THORNTON, W. M., D.Sc., Professor of Electrical Engineering in the Armstrong College, Newcastle-on-Tyne.
1902. ‡Thornycroft, Sir John I., F.R.S., M.Inst.C.E. Eyot Villa, Chiswick Mall, W.
1903. ‡Thorp, Edward. 87 Southbank-road, Southport.
1881. ‡Thorp, Fielden. Blossom-street, York.
1881. *Thorp, Josiah. 37 Pleasant-street, New Brighton, Cheshire.
1898. §Thorp, Thomas. Moss Bank, Whitefield, Manchester.
1898. ‡THORPE, JOCELYN FIELD, Ph.D., F.R.S. Victoria University, Manchester.
1871. ‡THORPE, Sir T. E., C.B., Ph.D., LL.D., F.R.S., F.R.S.E., V.P.C.S. (Pres. B, 1890; Council, 1886-92.) 61 Ladbroke-grove, W.
1899. §THRELFALL, RICHARD, M.A., F.R.S. Oakhurst, Church-road, Edgbaston, Birmingham.
1896. §THRIFT, WILLIAM EDWARD, M.A. (Local Sec. 1908), Professor of Natural and Experimental Philosophy in the University of Dublin. 80 Grosvenor-square, Rathmines, Dublin.
1904. §Thurston, Edgar, C.I.E. Government Museum, Madras.
1907. ‡Thwaites, R. E. 28 West-street, Leicester.
1889. ‡Thys, Colonel Albert. 9 Rue Briderode, Brussels.
1873. *TIDDEMAN, R. H., M.A., F.G.S. 298 Woodstock-road, Oxford.
1905. ‡Tietz, Heinrich, B.A., Ph.D. South African College, Cape Town.

Year of
Election.

1874. ‡TILDEN, Sir WILLIAM A., D.Sc., F.R.S., F.C.S. (Pres. B, 1888; Council, 1898-1904), Professor of Chemistry in the Imperial College of Science, London. The Oaks, Northwood, Middlesex.
1899. ‡Tims, H. W. Marett, M.A., M.D., F.L.S. 8 Brookside, Cambridge.
1902. ‡Tipper, Charles J. R., B.Sc. 21 Greenside, Kendal.
1905. ‡Tippett, A. M., M.Inst.C.E. Cape Government Railways, Cape Town.
1900. §Tocher, J. F., B.Sc., F.I.C. 5 Chapel-street, Peterhead, N.B.
1907. §Todd, Professor J. L. MacDonald College, Quebec, Canada.
1889. §Toll, John M. 49 Newsham-drive, Liverpool.
1905. ‡Tonkin, Samuel. Rosebank, near Cape Town.
1875. ‡Torr, Charles Hawley. 35 Burlington-road, Sherwood, Nottingham.
1909. ‡Tory, H. M. Edmonton, Alberta, Canada.
1901. ‡Townsend, J. S., M.A., F.R.S., Professor of Physics in the University of Oxford. New College, Oxford.
1876. *TRAIL, J. W. H., M.A., M.D., F.R.S., F.L.S. (Pres. K, 1910), Regius Professor of Botany in the University of Aberdeen.
1883. ‡TRAILL, A., M.D., LL.D., Provost of Trinity College, Dublin. Ballylough, Bushmills, Ireland.
1870. ‡TRAILL, WILLIAM A. Giant's Causeway Electric Tramway, Portrush, Ireland.
1868. ‡TRAQUAIR, RAMSAY H., M.D., LL.D., F.R.S., F.G.S. (Pres. D, 1900.) The Bush, Colinton, Midlothian.
1902. ‡Travers, Ernest J. Dunmurry, Co. Antrim.
1884. ‡Trechmann, Charles O., Ph.D., F.G.S. Hartlepool.
1908. §Treen, Henry M. Wicken, Soham, Cambridge.
1908. ‡Tremain, Miss Caroline P., B.A. Alexandra College, Dublin.
1910. §Tremearne, A. J. N. Tudor House, Blackheath Park, S.E.
1887. *Trench-Gascoigne, Mrs. F. R. Lotherton Hall, Parlington, Aberford, Leeds.
1903. ‡Trenchard, Hugh. The Firs, Clay Hill, Enfield.
1908. ‡Tresilian, R. S. Cumnor, Eglington-road, Dublin.
1905. ‡*TREVOR-BATTYE, A., M.A., F.L.S., F.R.G.S. Chilbolton, Stockbridge, R.S.O.*
1871. ‡TRIMEN, ROLAND, M.A., F.R.S., F.L.S., F.Z.S. Southbury, Lawn-road, Guildford.
1902. ‡Tristram, Rev. J. F., M.A., B.Sc. 20 Chandos-road, Chorlton-cum-Hardy, Manchester.
1884. *Trotter, Alexander Pelham. 8 Richmond-terrace, Whitehall, S.W.
1887. *TROUTON, FREDERICK T., M.A., Sc.D., F.R.S., Professor of Physics in University College, W.C.
1898. *Trow, Albert Howard, D.Sc., F.L.S., Professor of Botany in University College, Cardiff. 50 Clive-road, Penarth.
1885. *Tubby, A. H., F.R.C.S. 68 Harley-street, W.
1847. *Tuckett, Francis Fox. Frenchay, Bristol.
1905. §Turmeau, Charles. Claremont, Victoria Park, Wavertree, Liverpool.
1901. §Turnbull, Robert, B.Sc. Department of Agriculture and Technical Instruction, Dublin.
1893. ‡TURNER, DAWSON, M.D., F.R.S.E. 37 George-square, Edinburgh.
1894. *TURNER, H. H., M.A., D.Sc., F.R.S., F.R.A.S., Professor of Astronomy in the University of Oxford. The Observatory, Oxford.
1905. ‡Turner, Rev. Thomas. St. Saviour's Vicarage, 50 Fitzroy-street, W.

Year of Election

1886. *Turner, Thomas, M.Sc., A.R.S.M., F.I.C., Professor of Metallurgy in the University of Birmingham. Springfields, Upland-road, Selly Hill, Birmingham.
1863. *Turner, Sir William, K.C.B., LL.D., D.C.L., F.R.S., F.R.S.E. (President, 1900; Pres. H, 1889, 1897), Principal of the University of Edinburgh. 6 Eton-terrace, Edinburgh.
1910. §Turner, W. E. S. The University, Sheffield.
1890. *Turpin, G. S., M.A., D.Sc. High School, Nottingham.
1907. §Tutton, A. E. H., M.A., D.Sc., F.R.S. (Council, 1908– .) 41 Ladbroke-square, W.
1886. *Twigg, G. H. 6 & 7 Ludgate-hill, Birmingham.
1899. ‡Twisden, John R., M.A. 14 Gray's Inn-square, W.C.
1907. §Twyman, F. 75a Camden-road, N.W.
1865. ‡Tylor, Edward Burnett, D.C.L., LL.D., F.R.S. (Pres. H, 1884; Council, 1896–1902) Museum House, Oxford.
1883. ‡Tyrer, Thomas, F.C.S. Stirling Chemical Works, Abbey-lane, Stratford, E.

1884. *Underhill, G. E., M.A. Magdalen College, Oxford.
1903. ‡Underwood, Captain J. C 60 Scarisbrick New-road, Southport.
1908. §Unwin, Ernest Ewart, M.Sc. Bootham School, York.
1885. §Unwin, Howard. 1 Newton-grove, Bedford Park, Chiswick, W.
1883. §Unwin, John. Eastcliffe Lodge, Southport.
1876. *Unwin, W. C., F.R.S., M.Inst.C.E. (Pres. G, 1892; Council, 1892–99.) 7 Palace Gate-mansions, Kensington, W.
1909. ‡Urquhart, C. 239 Smith-street, Winnipeg, Canada.
1902. §Ussher, R. J. Cappagh House, Cappagh, Co. Waterford.
1880. ‡Ussher, W. A. E., F.G.S. 28 Jermyn-street, S.W.
1905. ‡Uttley, E. A., Electrical Inspector to the Rhodesian Government, Bulawayo.

1887. *Valentine, Miss Anne. The Elms, Hale, near Altrincham.
1908. ‡Valera, Edward de. University College, Blackrock, Dublin.
1905. ‡Van der Byl, J. A. P.O., Irene, Transvaal.
1865. *Varley, S. Alfred. Arrow Works, Jackson-road, Holloway, N.
1907. §Varley, W. Mansergh, M.A., D.Sc., Ph.D. Morningside, Eaton-crescent, Swansea.
1903. ‡Varwell, H. B. 2 Pennsylvania-park, Exeter.
1909. *Vassall, H., M.A. The Priory, Repton, Burton-on-Trent.
1907. §Vaughan, Arthur, B.A., D.Sc., F.G.S. 9 Pembroke-vale, Clifton, Bristol.
1895. ‡Vaughan, D. T. Gwynne, F.L.S. Queen's College, Belfast.
1905. ‡Vaughan, E. L. Eton College, Windsor.
1881. ‡Veley, V. H., M.A., D.Sc., F.R.S. 8 Marlborough-place, St. John's Wood, N.W.
1883. *Verney, Lady. Claydon House, Winslow, Bucks.
1904. *Vernon, H. M., M.A., M.D. 22 Norham-road, Oxford.
1896. *Vernon, Thomas T. Shotwick Park, Chester.
1896. *Vernon, William. Shotwick Park, Chester.
1890. *Villamil, Lieut.-Colonel R. de, R.E. Carlisle Lodge, Rickmansworth.
1906. *Vincent, J. H., M.A., D.Sc. L.C.C. Paddington Technical Institute, Saltram-crescent, W.
1899. *Vincent, Swale, M.D., D.Sc. (Local Sec. 1909), Professor of Physiology in the University of Manitoba, Winnipeg, Canada.

Year of Election.

1883. *VINES, SYDNEY HOWARD, M.A., D.Sc., F.R.S., F.L.S. (Pres. K 1900; Council, 1894–97), Professor of Botany in the University of Oxford. Headington Hill, Oxford.
1902. ‡Vinycomb, T. B. Sinn Fein, Shooters Hill, S.E.
1904. §Volterra, Professor Vito. Regia Universita, Rome.

1904. §Wace, A. J. B. Pembroke College, Cambridge.
1902. ‡Waddell, Rev. C. H. The Vicarage, Saintfield.
1909. ‡Wadge, Herbert W., M.D. 754 Logan-avenue, Winnipeg, Canada.
1888. ‡Wadworth, H. A. Breinton Court, near Hereford.
1890. §WAGER, HAROLD W. T., F.R.S., F.L.S. (Pres. K, 1905.) Hendre, Horsforth-lane, Far Headingley, Leeds.
1900. ‡Wagstaff, C. J. L., B.A. Grafton House, Oundle.
1902. ‡Wainwright, Joel. Finchwood, Marple Bridge, Stockport.
1906. ‡Wakefield, Charles. Heslington House, York.
1905. §Wakefield, Captain E. W. Stricklandgate House, Kendal.
1894. ‡WALFORD, EDWIN A., F.G.S. 21 West Bar, Banbury.
1882. *Walkden, Samuel, F.R.Met.S. The Cottage, Whitchurch, Tavistock.
1893. ‡Walker, Alfred O., F.L.S. Ulcombe-place, Maidstone, Kent.
1890. ‡Walker, A. Tannett. The Elms, Weetwood, Leeds.
1901. *Walker, Archibald, M.A., F.I.C. Newark Castle, Ayr, N.B.
1897. *WALKER, Sir B. E., C.V.O., D.C.L., F.G.S. (Local Sec. 1897.) Canadian Bank of Commerce, Toronto, Canada.
1904. §Walker, E. R. Nightingales, Adlington, Lancashire.
1891. ‡Walker, Frederick W. Tannett. Carr Manor, Meanwood, Leeds.
1905. ‡Walker, G. M. Lloyd's-buildings, Burg-street, Cape Town.
1894. *WALKER, G. T., M.A., D.Sc., F.R.S., F.R.A.S. Red Roof, Simla, India.
1897. ‡Walker, George Blake, M.Inst.C.E. Tankersley Grange, near Barnsley.
1906. ‡Walker, J. F. E. Gelson, B.A. 45 Bootham, York.
1894. *WALKER, JAMES, M.A. 30 Norham-gardens, Oxford.
1910. *Walker, James, D.Sc., F.R.S., Professor of Chemistry in the University of Edinburgh. 5 Wester Coates-road, Edinburgh.
1906. §Walker, Dr. Jamieson. 37 Charnwood-street, Derby.
1909. §Walker, Lewis D. 467 Cumberland-avenue, Winnipeg, Canada.
1907. ‡Walker, Philip F., F.R.G.S. 36 Prince's-gardens, S.W.
1908. *Walker, Robert. Westray, Combe Down, Bath.
1888. ‡Walker, Sydney F. 1 Bloomfield-crescent, Bath.
1896. §Walker, Colonel William Hall, M.P. Gateacre, Liverpool.
1910. §Wall, G. P., F.G.S. 32 Collegiate-crescent, Sheffield.
1883. ‡Wall, Henry. 14 Park-road, Southport.
1863. ‡WALLACE, ALFRED RUSSEL, O.M., D.C.L., F.R.S., F.L.S., F.R.G.S. (Pres. D, 1876; Council, 1870–72.) Broadstone, Wimborne, Dorset.
1905. ‡Wallace, R. W. 2 Harcourt-buildings, Temple, E.C.
1901. ‡Wallace, William, M.A., M.D. 25 Newton-place, Glasgow.
1887. *WALLER, AUGUSTUS D., M.D., F.R.S. (Pres. I, 1907.) 32 Grove End-road, N.W.
1905. §Waller, Mrs. 32 Grove End-road, N.W.
1889. *Wallis, Arnold J., M.A., 5 Belvoir-terrace, Cambridge.
1895. ‡WALLIS, E. WHITE, F.S.S. Royal Sanitary Institute and Parkes Museum, 90 Buckingham Palace-road, S.W.
1894. *WALMISLEY, A. T., M.Inst.C.E. 9 Victoria-street, Westminster, S.W.

Year of Election.

1891. §Walmsley, R. M., D.Sc. Northampton Institute, Clerkenwell, E.C.
1908. ‡Walsh, John M. Pleona Park-avenue, Sidney-parade, Dublin.
1895. ‡WALSINGHAM, The Right Hon. Lord, LL.D., F.R.S. Merton Hall, Thetford.
1902. *Walter, Miss L. Edna. 38 Woodberry-grove, Finsbury Park, N.
1904. *Walters, William, jun. Etheldreda House, Exning, Newmarket.
1887. ‡WARD, A. W., M.A., Litt.D., Master of Peterhouse, Cambridge.
1881. §Ward, George, F.C.S. Buckingham-terrace, Headingley, Leeds.
1874. ‡Ward, John, J.P., F.S.A. Beesfield, Farningham, Kent.
1905. ‡Warlow, Dr. G. P. 15 Hamilton-square, Birkenhead.
1884. *Warner, James D. 199 Baltic-street, Brooklyn, U.S.A.
1887. ‡WARREN, Lieut.-General Sir CHARLES, R.E., K.C.B., G.C.M.G., F.R.S., F.R.G.S. (Pres. E, 1887.) Athenæum Club, S.W.
1875. *WATERHOUSE, Major-General J. Hurstmead, Eltham, Kent.
1905. ‡Watermeyer, F. S., Government Land Surveyor. P.O. Box 973, Pretoria, South Africa.
1904. ‡Waters, A. H., B.A. 48 Devonshire-road, Cambridge.
1900. ‡*Waterston, David, M.D., F.R.S.E. 23 Colinton-road, Edinburgh.*
1875. ‡Watherston, Rev. Alexander Law, M.A., F.R.A.S. 2 Countess-road, Nuneaton.
1909. §Watkinson, Professor W. H. The University, Liverpool.
1884. ‡Watson, A. G., D.C.L. Uplands, Wadhurst, Sussex.
1901. *WATSON, ARNOLD THOMAS, F.L.S. Southwold, Tapton Crescent-road, Sheffield.
1886. *Watson, C. J. Alton Cottage, Botteville-road, Acock's Green, Birmingham.
1909. §Watson, Colonel Sir C. M., K.C.M.G., C.B., R.E., M.A. 16 Wilton-crescent, S.W.
1906. §Watson, D. M. S. Windlehurst, Anson-road, Victoria Park, Manchester.
1909. ‡Watson, Ernest Ansley, B.Sc. Alton Cottage, Botteville-road, Acock's Green, Birmingham.
1892. ‡Watson, G., M.Inst.C.E. Moorlands, Worcester.
1885. ‡Watson, Deputy Surgeon-General G.A. Hendre, Overton Park, Cheltenham.
1906. *Watson, Henry Angus. 3 Museum-street, York.
1889. ‡Watson, John, F.I.C. P.O. Box 1026, Johannesburg, South Africa.
1905. ‡Watson, Dr. R. W. Ladysmith, Cape Colony.
1894. *WATSON, Professor W., D.Sc., F.R.S. 7 Upper Cheyne-row, S.W.
1879. *WATSON, WILLIAM HENRY, F.C.S., F.G.S. Braystones House, Beckermet, Cumberland.
1901. §Watt, Henry Anderson. Ardenslate House, Hunter's Quay, Argyllshire.
1910. *Watts, Miss Beatrix, M.A. Girton College, Cambridge.
1875. *WATTS, JOHN, B.A., D.Sc. Merton College, Oxford.
1884. *Watts, Rev. Canon Robert R. The Red House, Bemerton, Salisbury.
1873. *WATTS, W. MARSHALL, D.Sc. Shirley, Venner-road, Sydenham, S.E.
1883. *WATTS, W. W., M.A., M.Sc., F.R.S., F.G.S. (Pres. C, 1903; Council, 1902-09), Professor of Geology in the Imperial College of Science and Technology, London, S.W.
1870. §Watts, William, M.Inst.C.E., F.G.S. Kenmore, Wilmslow, Cheshire.
1905. ‡Way, E. J. Post Office, Benoni, Transvaal.

Year of Election.

1905. ‡Way, W. A., M.A. The College, Graaf Reinet, South Africa.
1905. ‡Webb, Miss Dora. Gezina School, Pretoria.
1907. ‡Webb, Wilfred Mark. Odstock, Hanwell, W.
1891. ‡Webber, Thomas. 12 Southey-terrace, Wordsworth-avenue, Roath, Cardiff.
1910. §Webster, Professor Arthur G. Worcester, Massachusetts, U.S.A.
1909. ‡Webster, William, M.D. 1252 Portage-avenue, Winnipeg, Canada.
1908. §Wedderburn, Ernest Maclagan, F.R.S.E. 6 Succoth-gardens, Edinburgh.
1903. ‡Weekes, R. W., A.M.Inst.C.E. 65 Hayes-road, Bromley, Kent.
1890. *Weiss, F. Ernest, D.Sc., F.L.S., Professor of Botany in the Victoria University, Manchester.
1905. ‡Welby, Miss F. A. Hamilton House, Hall-road, N.W.
1902. ‡Welch, R. J. 49 Lonsdale-street, Belfast.
1894. ‡Weld, Miss. 119 Iffley-road, Oxford.
1880. *Weldon, Mrs. Merton Lea, Oxford.
1908. ‡Welland, Rev. C. N. Wood Park, Kingstown, Co. Dublin.
1881. §Wellcome, Henry S. Snow Hill-buildings, E.C.
1908. ‡Wellisch, E. M. 17 Park-street, Cambridge.
1881. ‡Wells, Rev. Edward, M.A. West Dean Rectory, Salisbury.
1881. *Wenlock, The Right Hon. Lord, G.C.S.I., G.C.I.E., K.C.B., LL.D. Escrick Park, Yorkshire.
Wentworth, Frederick W. T. Vernon. Wentworth Castle, near Barnsley, Yorkshire.
1864. *Were, Anthony Berwick. Roslyn, Walland's Park, Lewes.
1886. *Wertheimer, Julius, B.A., B.Sc., F.C.S., Principal of and Professor of Chemistry in the Merchant Venturers' Technical College, Bristol.
1910. §West, G. S., M.A., D.Sc., Professor of Botany in the University of Birmingham.
1900. §West, William, F.L.S. 26 Woodville-terrace, Horton-lane, Bradford.
1903. §Westaway, F. W. 1 Pemberley-crescent, Bedford.
1882. *Westlake, Ernest, F.G.S. Fordingbridge, Salisbury.
1900. ‡Wethey, E. R., M.A., F.R.G.S. 4 Cunliffe-villas, Manningham, Bradford.
1909. §Wheeler, A. O., F.R.G.S. The Alpine Club of Canada, Sidney, B.C., Canada.
1878. *Wheeler, W. H., M.Inst.C.E. 4 Hope-park, Bromley, Kent.
1888. §Whelen, John Leman. 23 Fairhazel-gardens, N.W.
1893. *Whetham, W. C. D., M.A., F.R.S. Upwater Lodge, Cambridge.
1888. *Whidborne, Miss Alice Maria. Charanté, Torquay.
1898. *Whipple, Robert S. Scientific Instrument Company, Cambridge.
1883. *Whitaker, T. Walton House, Burley-in-Wharfedale.
1859. *Whitaker, William, B.A., F.R.S., F.G.S. (Pres. C, 1895; Council, 1890–96.) 3 Campden-road, Croydon.
1884. ‡Whitcher, Arthur Henry. Dominion Lands Office, Winnipeg, Canada.
1886. ‡Whitcombe, E. B. Borough Asylum, Winson Green, Birmingham.
1897. ‡Whitcombe, George. The Wotton Elms, Wotton, Gloucester.
1886. ‡White, A. Silva. Lee-on-Solent, Hants.
1908. ‡White, Mrs. A. Silva. Lee-on-Solent, Hants.
1904. ‡White, H. Lawrence, B.A. 33 Rossington-road, Sheffield.
1885. *White, J. Martin. Balruddery, Dundee.
1905. ‡White, Miss J. R. Huguenot College, Wellington, Cape Colony.
1910. *White, Mrs. Jessie, D.Sc., B.A. 4 Elthorne-mansions, Upper Holloway, N.

Year of Election.

1897. *WHITE, Sir W. H., K.C.B., F.R.S. (Pres. G, 1899, 1909; Council, 1897–1900, 1910– .) Cedarcroft, Putney Heath, S.W.
1877. *White, William. 20 Hillersdon-avenue, Church-road, Barnes, S.W.
1904. ‡WHITEHEAD, J. E. L., M.A. (Local Sec. 1904). Guildhall, Cambridge.
1905. §Whiteley, Miss M. A., D.Sc. Imperial College of Science, S.W.
1893. §Whiteley, R. Lloyd, F.C.S., F.I.C. Municipal Science and Technical School, West Bromwich.
1907. *Whitley, E. Clovelly, Sefton Park, Liverpool.
1905. *Whitmee, H. B. P.O. Box 470, Durban, Natal.
1891. ‡Whitmell, Charles T., M.A., B.Sc. Invermay, Hyde Park, Leeds.
1897. ‡WHITTAKER, E. T., M.A., F.R.S., Royal Astronomer of Ireland and Andrews Professor of Astronomy in the University of Dublin. The Observatory, Dunsink, Co. Dublin.
1901. ‡Whitton, James. City-chambers, Glasgow.
1857. *WHITTY, Rev. JOHN IRWINE, M.A., D.C.L., LL.D. 13 Granville Marina, Ramsgate.
1905. ‡Whyte, B. M. Simon's Town, Cape Colony.
1905. §Wibberley, C. Beira and Mashonaland Railways, Umtali, South Africa.
1889. *WILBERFORCE, L. R., M.A., Professor of Physics in the University of Liverpool.
1887. *WILDE, HENRY, D.Sc., D.C.L., F.R.S. The Hurst, Alderley Edge, Cheshire.
1905. ‡Wiley, J. R. Kingsfold, Mill-street, Cape Town.
1910. §Wilkins, C. F. Care of Messrs. King & Co., Pall Mall, S.W.
1905. ‡Wilkins, R. F. Thatched House Club, St. James's-street, S.W.
1904. §Wilkinson, Hon. Mrs. Dringhouses Manor, York.
1900. §Wilkinson, J. B. Holme-lane, Dudley Hill, Bradford.
1903. ‡Willett, John E. 3 Park-road, Southport.
1904. *Williams, Miss Antonia. 6 Sloane-gardens, S.W.
1861. *Williams, Charles Theodore, M.V.O., M.A., M.D. 2 Upper Brook-street, Grosvenor-square, W.
1905. §Williams, Gardner F. 2201 R-street, Washington, D.C., U.S.A.
1883. ‡Williams, Rev. H. Alban, M.A. Sheering Rectory, Harlow, Essex.
1861. *Williams, Harry Samuel, M.A., F.R.A.S. 6 Heathfield, Swansea.
1875. *Williams, Rev. Herbert Addams. Llangibby Rectory, near Newport, Monmouthshire.
1891. §Williams, J. A. B., M.Inst.C.E. The Hurst, Branksome Park, Bournemouth.
1883. *Williams, Mrs. J. Davies. 5 Chepstow-mansions, Bayswater, W.
1888. *Williams, Miss Katharine T. Llandaff House, Pembroke-vale, Clifton, Bristol.
1901. *Williams, Miss Mary. 6 Sloane-gardens, S.W.
1891. ‡Williams, Morgan. 5 Park-place, Cardiff.
1883. ‡Williams, T. H. 27 Water-street, Liverpool.
1877. *WILLIAMS, W. CARLETON, F.C.S. Broomgrove, Goring-on-Thames.
1906. ‡Williams, W. F. Lobb. 32 Lowndes-street, S.W.
1857. ‡WILLIAMSON, BENJAMIN, M.A., D.C.L., F.R.S. Trinity College, Dublin.
1894. *Williamson, Mrs. Janora. 18 Rosebery-gardens, Crouch End, N.
1910. §Williamson, K. B., Central Provinces, India. Care of Messrs. Grindlay & Co., 54 Parliament-street, S.W.
1895. ‡WILLINK, W. (Local Sec. 1896.) 14 Castle-street, Liverpool.
1895. ‡Willis, John C., M.A., F.L.S., Director of the Royal Botanical Gardens, Peradeniya, Ceylon.
1896. ‡WILLISON, J. S. (Local Sec. 1897.) Toronto, Canada.

Year of
Election.

1859. *Wills, The Hon. Sir Alfred. Saxholm, Basset, Southampton.
1899. §Willson, George. Lenderac, Sedlescombe-road South, St. Leonards-on-Sea.
1899. §Willson, Mrs. George. Lenderac, Sedlescombe-road South, St. Leonards-on-Sea.
1908. §Wilson, Miss. Grove House, Paddock, Huddersfield.
1901. ‡Wilson, A. Belvoir Park, Newtownbreda, Co. Down.
1886. ‡*Wilson, Alexander B. Holywood, Belfast.*
1878. ‡Wilson, Professor Alexander S., M.A., B.Sc. United Free Church Manse, North Queensferry.
1905. §Wilson, A. W. P.O. Box 24, Langlaagte, South Africa.
1907. §Wilson, A. W. Low Slack, Queen's-road, Kendal.
1903. ‡Wilson, C. T. R., M.A., F.R.S. Sidney Sussex College, Cambridge.
1894. *Wilson, Charles J., F.I.C., F.C.S. 14 Old Queen-street, Westminster, S.W.
1904. §Wilson, Charles John, F.R.G.S. Deanfield, Hawick, Scotland.
1904. §Wilson, David, M.D. Grove House, Paddock, Huddersfield.
1900. *Wilson, Duncan R. 109A Whitehall-court, S.W.
1903. ‡Wilson, George. The University, Leeds.
1895. ‡Wilson, Dr. Gregg. Queen's College, Belfast.
1901. ‡Wilson, Harold A., M.A., D.Sc., F.R.S., Professor of Physics in McGill University, Montreal, Canada.
1902. *Wilson, Harry, F.I.C. 32 Westwood-road, Southampton.
1879. ‡Wilson, Henry J., M.P., Osgathorpe Hills, Sheffield.
1910. §Wilson, J. S. 5 Regency House, Regent-place, Westminster, S.W.
1908. ‡Wilson, Professor James, M.A., B.Sc. Cluny, Orwell Park, Dublin.
1865. ‡WILSON, Ven. Archdeacon JAMES M., M.A., F.G.S. The Vicarage, Rochdale.
1879. ‡Wilson, John Wycliffe. Easthill, East Bank-road, Sheffield.
1901. *Wilson, Joseph. Hillside, Avon-road, Walthamstow, N.E.
1908. *Wilson, Malcolm, B.Sc. Royal College of Science, S.W.
1909. §Wilson, R. A. Hinton, Londonderry.
1903. ‡Wilson, Dr. R. Arderne. Saasveld House, Kloof-street, Cape Town.
1847. *Wilson, Rev. Sumner. Preston Candover Vicarage, Basingstoke.
1883. ‡Wilson, T. Rivers Lodge, Harpenden, Hertfordshire.
1892. ‡Wilson, T. Stacey, M.D. 27 Wheeley's-road, Edgbaston, Birmingham.
1887. §Wilson, W., jun. Battlehillock, Kildrummy, Mossat, Aberdeenshire.
1909. ‡Wilson, W. Murray. 29 South Drive, Harrogate.
1910. §Wilton, T. R., M.A., Assoc. M.Inst.C.E. 18 Westminster-chambers, Crosshall-street, Liverpool.
1907. §Wimperis, H. E., M.A. 28 Rossetti Garden-mansions, S.W.
1910. §Winder, B. W. Ceylon House, Sheffield.
1886. ‡WINDLE, BERTRAM C. A., M.A., M.D., D.Sc., F.R.S., President of Queen's College, Cork.
1863. *WINWOOD, Rev. H. H., M.A., F.G.S. (Local Sec. 1864.) 11 Cavendish-crescent, Bath.
1905. §Wiseman, J. G., F.R.C.S., F.R.G.S. Stranraer, St. Peter's-road, St. Margaret's-on-Thames.
1875. ‡WOLFE-BARRY, Sir JOHN, K.C.B., F.R.S., M.Inst.C.E. (Pres. G, 1898; Council, 1899–1903, 1909–10.) Dartmouth House, 2 Queen Anne's-gate, Westminster, S.W.
1905. ‡Wood, A., jun. Emmanuel College, Cambridge.
1863. *Wood, Collingwood L. Freeland, Forgandenny, N.B.
1875. *Wood, George William Rayner. Singleton Lodge, Manchester.
1908. §Wood, Henry J. 4 Elsworthy-road, N.W.

Year of Election.

1878. ‡Wood, Sir H. Trueman, M.A. Royal Society of Arts, John-street, Adelphi, W.C.; and Prince Edward's-mansions, Bayswater, W.
1883. *Wood, J. H. 21 Westbourne-road, Birkdale, Lancashire.
1904. *Wood, T. B., M.A., Professor of Agriculture in the University of Cambridge. Caius College, Cambridge.
1899. *Wood, W. Hoffman. Ben Rhydding, Yorkshire.
1901. *Wood, William James, F.S.A.(Scot.) 266 George-street, Glasgow.
1899. *Woodcock, Mrs. E. M. Care of Messrs. Stilwell & Harley, 4 St. James'-street, Dover.
1896. *Woodhead, Professor G. Sims, M.D. Pathological Laboratory, Cambridge.
1888. **Woodiwiss, Mrs. Alfred.* 121 *Castlenau, Barnes, S.W.*
1906. ‡Woodland, W. N. F. University College, Gower-street, W.C.
1904. §Woodrow, John. Berryknowe, Meikleriggs, Paisley.
1904. ‡Woods, Henry, M.A. St. John's College, Cambridge.
Woods, Samuel. 1 Drapers'-gardens, Throgmorton-street, E.C.
1887. *Woodward, Arthur Smith, LL.D., F.R.S., F.L.S., F.G.S. (Pres. C, 1909; Council, 1903-10), Keeper of the Department of Geology, British Museum (Natural History), Cromwell-road, S.W.
1869. *Woodward, C. J., B.Sc., F.G.S. The Lindens, St. Mary's-road, Harborne, Birmingham.
1886. ‡Woodward, Harry Page, F.G.S. 129 Beaufort-street, S.W.
1866. ‡Woodward, Henry, LL.D., F.R.S., F.G.S. (Pres. C, 1887; Council, 1887-94.) 13 Arundel-gardens, Notting Hill, W.
1870. ‡Woodward, Horace B., F.R.S., F.G.S. 85 Coombe-road, Croydon.
1894. *Woodward, John Harold. 8 Queen Anne's-gate, Westminster, S.W.
1909. *Woodward, Robert S. Carnegie Institution, Washington, U.S.A.
1908. §Woolacott, David, D.Sc., F.G.S. 8 The Oaks West, Sunderland.
1890. *Woollcombe, Robert Lloyd, M.A., LL.D., F.I.Inst., F.R.C.Inst., F.R.G.S., F.R.E.S., F.S.S., M.R.I.A. 14 Waterloo-road, Dublin.
1883. *Woolley, George Stephen. Victoria Bridge, Manchester.
1908. §Worsdell, W. C. 2 Woodside, Bathford, Bath.
1863. *Worsley, Philip J. Rodney Lodge, Clifton, Bristol.
1901. ‡Worth, J. T. Oakenrod Mount, Rochdale.
1904. §Worthington, A. M., C.B., F.R.S. 1 The Paragon, Blackheath, S.E.
1908. *Worthington, James H., B.A., F.R.A.S. Wycombe Court, High Wycombe.
1906. ‡Wragge, R. H. Vernon. York.
1910. §Wrench, E. G. Park Lodge, Baslow, Derbyshire.
1896. ‡Wrench, Edward M., M.V.O., F.R.C.S. Park Lodge, Baslow, Derbyshire.
1905. ‡Wrentmore, G. G. Marva, Silwood-road, Rondebosch, Cape Colony.
1906. ‡Wright, Sir A. E., M.D., D.Sc., F.R.S. 6 Park-crescent, W.
1905. ‡Wright, Allan. Struan Villa, Gardens, Cape Town.
1883. *Wright, Rev. Arthur, D.D. Queens' College, Cambridge.
1909. ‡Wright, C. S., B.A. Caius College, Cambridge.
1905. *Wright, FitzHerbert. The Hayes, Alfreton.
1874. ‡Wright, Joseph, F.G.S. 4 Alfred-street, Belfast.
1884. ‡Wright, Professor R. Ramsay, M.A., B.Sc. University College, Toronto, Canada.
1904. ‡Wright, R. T. Goldieslie, Trumpington, Cambridge.
1903. ‡Wright, William. The University, Birmingham.

Year of Election.

1871. ‡WRIGHTSON, Sir THOMAS, Bart., M.Inst.C.E., F.G.S. Neasham Hall, Darlington.
1902. ‡Wyatt, G. H. 1 Maurice-road, St. Andrew's Park, Bristol.
1901. ‡Wylie, Alexander. Kirkfield, Johnstone, N.B.
1902. ‡Wylie, John. 2 Mafeking-villas, Whitehead, Belfast.
1899. ‡WYNNE, W. P., D.Sc., F.R.S., Professor of Chemistry in the University of Sheffield. 17 Taptonville-road, Sheffield.

1905. ‡Yallop, J. Allan. Alandale, London-road, Sea Point, Cape Colony.
1901. *Yapp, R. H., M.A., Professor of Botany in University College, Aberystwyth.
. *Yarborough, George Cook. Camp's Mount, Doncaster.
1894. *Yarrow, A. F. Campsie Dene, Blanefield, Stirlingshire.
1905. ‡Yerbury, Colonel. Army and Navy Club, Pall Mall, S.W.
1909. §Young, Professor A. H. Trinity College, Toronto, Canada.
1904. ‡Young, Alfred. Selwyn College, Cambridge.
1891. §Young, Alfred C., F.C.S. 17 Vicar's-hill, Lewisham, S.E.
1905. ‡Young, Professor Andrew, M.A., B.Sc. South African College, Cape Town.
1909. ‡Young, F. A. 615 Notre Dame-avenue, Winnipeg, Canada.
1894. *YOUNG, GEORGE, Ph.D. 79 Harvard-court, Honeybourne-road, N.W.
1909. §Young, Herbert, M.A., B.C.L., F.R.G.S. Arnprior, Ealing, W.
1901. *Young, John. 2 Montague-terrace, Kelvinside, Glasgow.
1905. ‡Young, Professor R. B. Transvaal Technical Institute, Johannesburg.
1885. ‡YOUNG, R. BRUCE, M.A., M.B. 8 Crown-gardens, Dowanhill, Glasgow.
1909. ‡Young, R. G. University of North Dakota, North Chautauqua, North Dakota, U.S.A.
1901. ‡Young, Robert M., B.A. Rathvarna, Belfast.
1883. *YOUNG, SYDNEY, D.Sc., F.R.S. (Pres. B, 1904), Professor of Chemistry in the University of Dublin. 12 Raglan-road, Dublin.
1887. ‡Young, Sydney. 29 Mark-lane, E.C.
1907. *YOUNG, WILLIAM HENRY, M.A., Sc.D., F.R.S. La Nonette de la Forêt, Geneva, Switzerland.
1903. ‡Yoxall, Sir J. H., M.P. 67 Russell-square, W.C.

CORRESPONDING MEMBERS.

Year of Election.

1887. Professor Cleveland Abbe. Local Office, U.S.A. Weather Bureau, Washington, U.S.A.
1892. Professor Svante Arrhenius. The University, Stockholm. (Bergsgatan 18.)
1897. Professor Carl Barus. Brown University, Providence, R.I., U.S.A.
1887. Hofrath Professor A. Bernthsen, Ph.D. Anilenfrabrik, Ludwigshafen, Germany.
1892. Professor M. Bertrand. 75 rue de Vaugirard, Paris.
1894. Deputy Surgeon-General J. S. Billings. 40 Lafayette-place, New York, U.S.A.
1893. Professor Christian Bohr. Bredgade 62, Copenhagen, Denmark.
1887. Professor Lewis Boss. Dudley Observatory, Albany, New York, U.S.A.
1884. Professor H. P. Bowditch, M.D., LL.D. Harvard Medical School, Boston, Massachusetts, U.S.A.
1890. Professor Dr. L. Brentano. Friedrichstrasse 11, München.
1893. Professor Dr. W. C. Brögger. Universitets Mineralogske Institute, Christiania, Norway.
1887. Professor J. W. Brühl. Heidelberg.
1884. Professor George J. Brush. Yale University, New Haven, Conn., U.S.A.
1894. Professor D. H. Campbell. Stanford University, Palo Alto, California, U.S.A.
1897. M. C. de Candolle. 3 Cour de St. Pierre, Geneva, Switzerland.
1887. Professor G. Capellini. 65 Via Zamboni, Bologna, Italy.
1887. Hofrath Dr. H. Caro. C. 8, No. 9, Mannheim, Germany.
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